CHEMICAL ENGINEERING

February 2020

ESSENTIALS FOR THE CPI PROFESSIONAL

www.chemengonline.com

Effective Process Safety

Modern Pump Monitoring

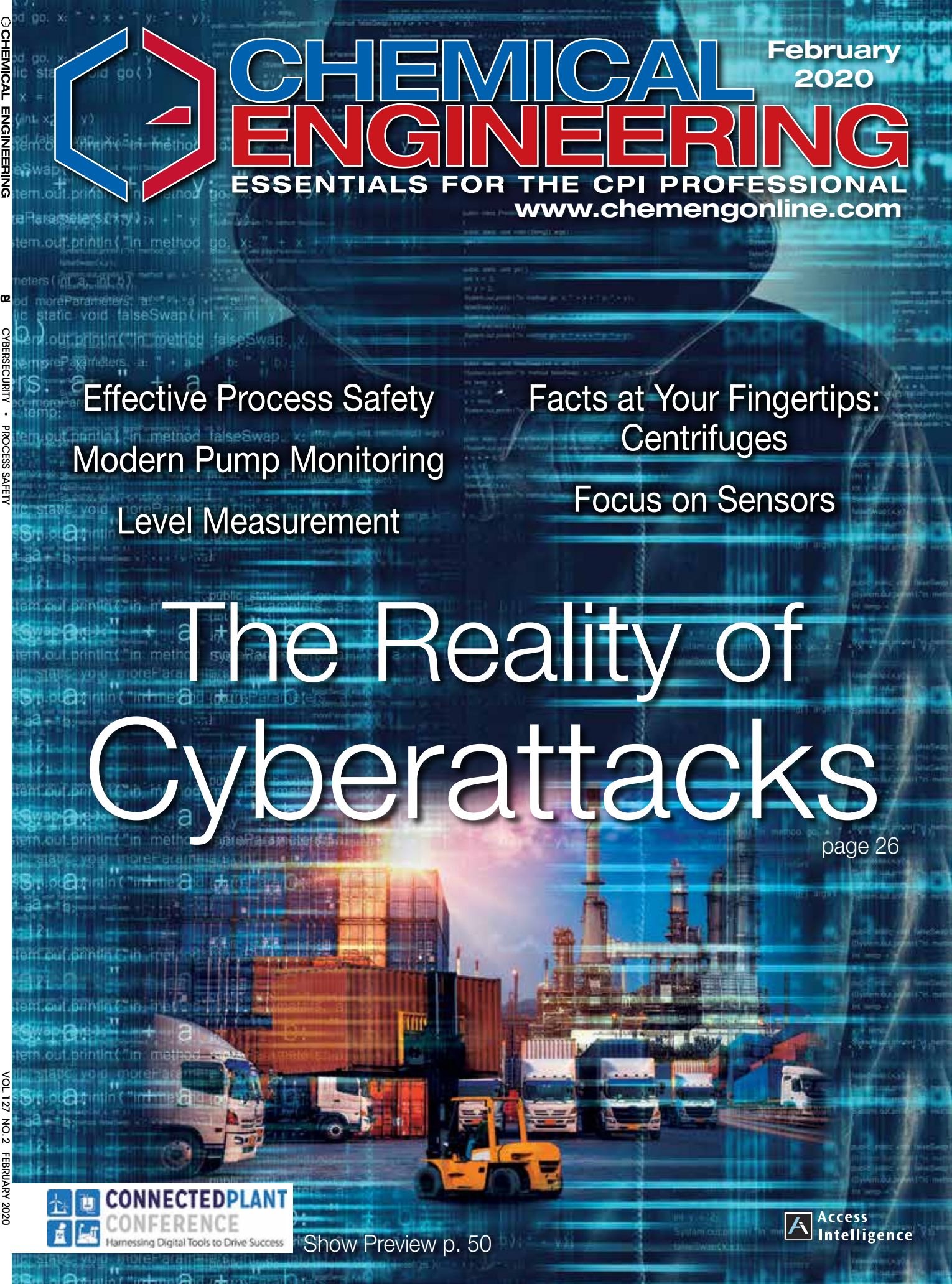
Level Measurement

Facts at Your Fingertips: Centrifuges

Focus on Sensors

The Reality of Cyberattacks

page 26



Show Preview p. 50

Access Intelligence

CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL
www.chemengonline.com

February 2020 Volume 127 | no. 2

Cover Story

26

In the News

32

14

38

Technical and Practical

20

22

50

Equipment and Services

Departments

Advertisers

Chemical Connections

Follow @ChemEngMag on Twitter

Join the *Chemical Engineering* Magazine LinkedIn Group

Visit us on www.chemengonline.com for more articles, Latest News, Webinars, Test your Knowledge Quizzes, Bookshelf and more

Coming in March

Look for: **Feature Reports** on Rotating Machinery; and the Circular Economy; A **Focus** on Corrosion; A **Facts at your Fingertips** on Chemical Reactivity; a **News Article** on Pressure-Relief Devices; **New Products**; and much more

Cover design: Rob Hudgins

CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL

HEADQUARTERS

40 Wall Street, 50th floor, New York, NY 10005, U.S.
Tel: 212-621-4900
Fax: 212-621-4694

EUROPEAN EDITORIAL OFFICES

Zeilweg 44, D-60439 Frankfurt am Main, Germany
Tel: 49-69-9573-8296
Fax: 49-69-5700-2484

CIRCULATION REQUESTS:

Tel: 800-777-5006
Fax: 301-309-3847
Chemical Engineering, 9211 Corporate Blvd.,
4th Floor, Rockville, MD 20850
email: clientservices@accessintel.com

ADVERTISING REQUESTS: SEE P. 54

ACCESS INTELLIGENCE, LLC

DON PAZOUR
Chief Executive Officer

HEATHER FARLEY
Chief Operating Officer

JAMES OGLE
Executive Vice President
& Chief Financial Officer

MACY L. FECTO
Chief People Officer

JENNIFER SCHWARTZ
Senior Vice President & Group Publisher
Aerospace, Energy, Healthcare

ROB PACIOREK
Senior Vice President,
Chief Information Officer

JONATHAN RAY
Vice President, Digital

MICHAEL KRAUS
Vice President,
Production, Digital Media & Design

GERALD STASKO
Vice President/Corporate Controller

Access Intelligence
9211 Corporate Blvd., 4th Floor
Rockville, MD 20850-3240
www.accessintel.com

BPA

Editor's Page

3D printing gains momentum

In today's accelerating adoption of new digital technologies, one of the areas that is rapidly gaining momentum, and the interest of the chemical process industries (CPI), is additive manufacturing (AM) — more commonly referred to as 3D printing.

According to Formlabs (www.formlabs.com), a 3D-printing company headquartered in Massachusetts, the 3D-printing market had sales of $6 billion in 2017 and is projected to grow to a market size of $22 billion by 2022. One big advantage of 3D printing is that it can increase the efficiency of maintenance activities, making it less expensive and faster to create replacement parts and customized products. Reduced costs, less waste and more environmentally friendly operations are some of the benefits attributed to this technology.

The CPI invest in 3D printing

In addition to the benefits of using 3D technology in their own businesses, the CPI are suppliers of new materials for this booming field and are directly influencing its growth.

Arkema (www.arkema.com) recently inaugurated a Global Center of Excellence for 3D Printing in Normandy, France. The center will be dedicated to AM by powder-bed fusion, based on high-performance polymers. The new center is said to complement the company's two other centers, both in Pennsylvania, for photocure liquid resins and for filament extrusion. The company says its "investments in 3D-printing innovation represent several tens of millions of euros per year."

BASF (www.basf.com) announced in November that it was acquiring Sculpteo, an online 3D-printing service provider to enhance BASF's ability to provide innovative industrial 3D printing solutions. Sculpteo (www.sculpteo.com) issues an annual report called the State of 3D Printing, which can be found on its website.

Covestro (www.covestro.com) is upgrading its laboratories for 3D printing at its Leverkusen, Pittsburgh and Shanghai sites, where in collaboration with customers, it develops and tests materials for AM. Covestro supplies polycarbonate for the 3D-printing manufacture of light fixtures — which it says is a highly flexible and more sustainable way to manufacture these items.

Much more news and latest developments about the CPI and AM can be found on our website (www.chemengonline.com).

Developments in biomaterials

Developments in AM are moving beyond the realm of plastics, metals and ceramics to bio-based materials. Last month, the Lonza Group (www.lonza.com) and Allevi (www.allevi3d.com) announced that they were collaborating on 3D bioprinting — a promising technology for engineering complex tissues needed for pharmaceutical research.

Recently, researchers at Rensselear Polytechnic Institute (www.rpi.edu) reported developments in 3D-printed living skin, complete with blood vessels. And, researchers at Harvard's Wyss Institute for Biologically Inspired Engineering (wyss.harvard.edu), and the John A. Paulson School of Engineering and Applied Sciences reported a new technique called SWIFT (sacrificial writing into functional tissue) that is said to yield organ-specific tissues, which the researchers say could ultimately be used to repair human organs.

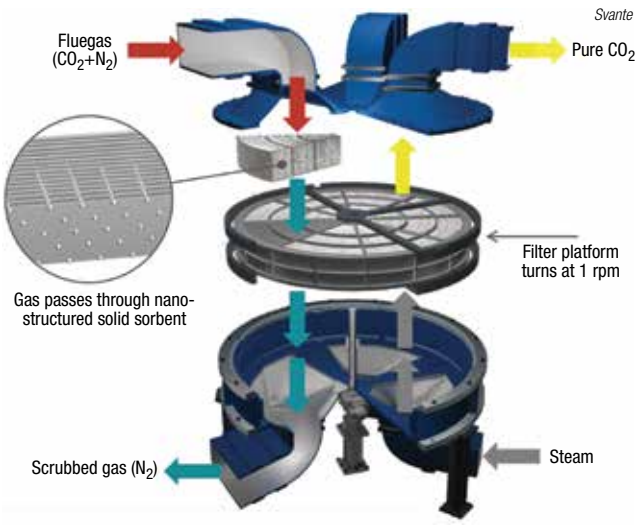
Still in its early years of development, 3D printing offers new possibilities across a broad spectrum of applications with promising opportunities for the CPI. ■

Dorothy Lozowski, Editorial Director

Edited by:
Gerald Ondrey

New project aims to scale up rapid carbon-capture process

A new project is exploring a unique large-scale carbon-capture facility in the U.S. Technology developer Svante, Inc. (Burnaby, B.C., Canada; www svanteinc.com), is working with Lafarge-Holcim, Oxy Low Carbon Ventures, LLC and Total S.A., to evaluate the construction of a facility that will capture up to 725,000 metric tons per year of carbon dioxide from LafargeHolcim's cement plant in Florence, Colorado. The facility would be the first large-scale commercial application of Svante's carbon-capture process, which employs tailor-made nanomaterials instead of conventional liquid solvents.



"We are using nanomaterials called solid sorbents with a very high storage capacity for CO_2," explains Claude Letourneau, president and CEO of Svante. The company engineered these materials to capture and release CO_2 in less than one minute, whereas traditional technology may take hours. According to Letourneau, this faster turnover time means that a much smaller volume of sorbent material is required, resulting in a much more intensified process and lower capital costs relative to traditional processes, such as liquid-solvents. Svante has also developed a rotating device with laminated filter structures to capture and release the CO_2 and regenerate the sorbent in a single modular unit (diagram). This modular setup provides a smaller footprint than other technologies, which typically use three separate pieces of equipment.

Svante has patented the process, which is based on direct, rapid temperature-swing adsorption using fast kinetic materials and processes to control oxidation, water and CO_2 degradation, along with avoiding the sorbent attrition associated with other adsorption approaches, says Letourneau. The company is currently using three classes of sorbent materials tailored for specific applications: silica doped with amines for natural-gas boiler fluegas; a metal organic framework (MOF) with high resistance to oxidation for cement applications; and a porous polymer network/MOF with high CO_2 capacity at very low concentration for direct-air capture. Svante currently operates two pilot plants in Canada and one in France, the largest of which captures 30 tons/d of CO_2. "We are currently designing a first-of-its-kind commercial-scale machine capable of capturing up to 325,000 tons per year," adds Letourneau.

ULTRATHIN MEMBRANE

Researchers led by professors Hideto Matsuyama and Tomohisa Yoshioka at Kobe University's Research Center for Membrane and Film Technology (Japan; www.research.kobe-u.ac.jp) have developed an ultrathin, fouling-resistant membrane that separates oil from water. Described in a recent issue of the *J. of Materials Chemistry A*, the membrane consists of a porous polyketone (PK) support with a 10-nm-thick silica layer applied to the top surface.

The PK membrane is highly permeable to water due to the presence of large pores and a high porosity. The silica layer provides a strong oil-repellent coating to protect the membrane from fouling. The new membrane is able to reject 99.9% of oil droplets, including those with a size of 10 nm. A 1-m^2 membrane operating at 1 atm pressure is capable of processing 6,000 L/h of wastewater, and has been shown to separate a wide range of oily emulsions.

BIO-BASED PRODUCTS

Last month at the Heimtextil trade show (Frankfurt am Main, Germany; January 7–10), Devan Chemicals N.V. (Ronse, Belgium; www.

(Continues on p. 10)

Reduce the humidity and make some electricity on the side

Researchers at the Dept. of Materials Science and Engineering, National University of Singapore (www.nus.edu.sg), led by professor Swee Ching Tan, have combined a moisture-absorbent gel with light-active materials to develop a humidity "digester" that dries ambient air while generating energy. The researchers note that humans' perception of temperature is highly influenced by relative humidity (RH). When the RH is low, our perception of the temperature is much lower than in the case of high RH.

The humidity digester is composed of a super-hygroscopic zinc and cobalt hydrogel (which absorbs water), a cathode, a photoanode and a solar cell. The researchers developed a ferroelectric-semiconductor photoanode ($BaTiO_3$@$BiVO_4$) that, acting as a photo-electrocatalyst, oxidizes the absorbed water in the presence of light to split water and produce energy. The hydrogel constantly replenishes the system with water pulled out of the air to sustain the energy-generation process.

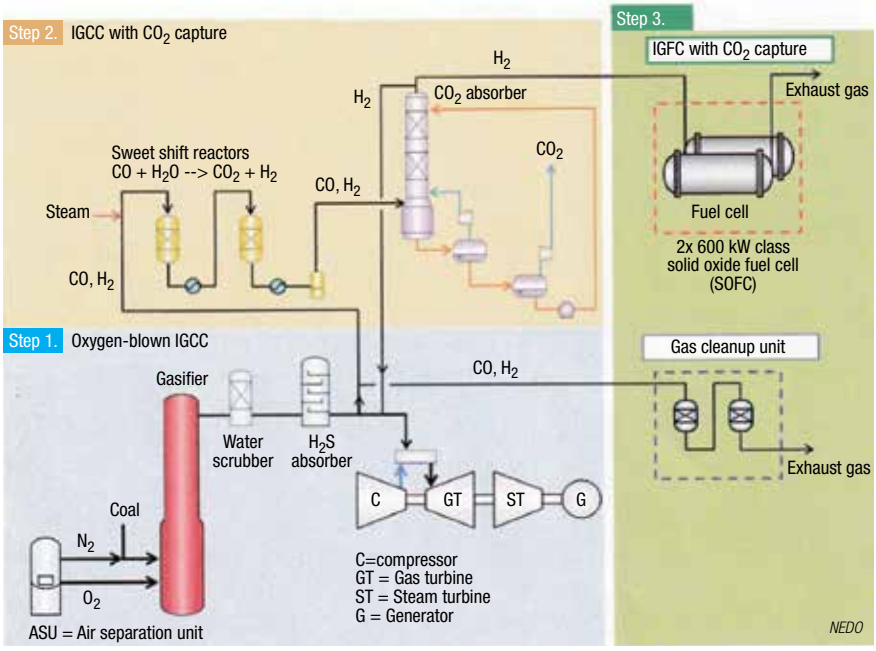
Combining the photoanode-hydrogel device with a solar cell, the RH is reduced by 12%, while a photocurrent of about 0.4 mA/cm^2 is simultaneously generated under an illumination of 10 mW/cm^2. This current is relatively low, but compared with commercial air-conditioning units, the digester can improve thermal comfort with significantly less energy input. According to the researchers, even after scaling the device up to commercial standards, it will be easier to install, it is portable, and its operation will cost a fraction of the cost of operating an air conditioner.

Japanese 'clean coal' demonstration project takes a step further

Construction has begun on the third step of a project to demonstrate the world's first integrated coal-gasification fuel-cell (IGFC) combined cycle power plant with CO_2 capture. The five-year, $73.3-million project is a collaboration of the New Energy and Industrial Technology Development Organization (NEDO; Kawasaki City; www.nedo.go.jp) and Osaki CoolGen Corp. (Hiroshima Prefecture, both Japan; www.osaki-coolgen.jp). IGFC technology has the potential to reach a 55% thermal efficiency (higher heating value; HHV).

The IGFC demonstration project is composed of three steps (diagram): (1) the demonstration of oxygen-blown integrated coal-gasification combined-cycle (O_2-blown IGCC), which was completed in March 2019; (2) the demonstration of O_2-blown IGCC with CO_2 separation and capture, which started in December 2019; and (3) the demonstration of IGFC with CO_2 separation and capture.

For the first step, a 170,000 kW-class demonstration test facility was constructed within the grounds of the Osaki Power Station of The Chugoku Electric Power Co. During the demonstration tests, coal particles were used to operate a 1,300°C-class gas turbine, while using the heat generated to operate a steam turbine for combined-cycle power generation. The performance, operability, reliability, and economic feasibility as a coal-fired power generation system was verified. The targeted thermal efficiency of 40.5% HHV was achieved for an O_2-blown IGCC using a 100°C-class gas turbine. They are forecasting a net thermal efficiency of approximately 46% will be achieved for a commercial plant that uses a 1,500°C-class gas turbine. Based on these results, they are expecting to reduce CO_2 emissions by about 15% compared to ultra-supercritical (USC) pressure pulverized-coal-fired power generation.



To demonstrate the second step, construction work on the CO_2-capture unit was completed last summer, and testing started in December 2019 and will continue through 2020. Meanwhile, construction has also begun on the third step, in which the fuel cell will be added to the O_2-blown IGCC to demonstrate the complete IGFC with CO_2 capture, which should begin late 2021 and run through 2022. Ultimately, the project aims to achieve a net thermal efficiency of approximately 47%, while capturing 90% of the CO_2, and a 40% of transmission end efficiency when applied to a 500-MW-class commercial unit.

Making renewable H_2 for export

A large renewable-hydrogen production facility, called the Murchison House Station, near the coastal town of Kalbarri, has been unveiled for Western Australia, with plans for up to 5 GW of a combined solar and wind project. The project has been proposed by Hydrogen Renewables Australia (www.renewablehydrogen.com.au) — a renewable energy company combining wind and solar resources to produce 100% renewable H_2 for export, primarily to Japan and South Korea. The strategic co-location of renewable sources aims to improve the cost-effectiveness of the production of electricity, due to the fact that, in that location, solar energy is available during the day, while strong wind energy is available mainly at night.

The project will be undertaken in three phases, including a demonstration phase for the production of transport fuels, the production of hydrogen fuels for natural gas blending in the Western Australian gas grid, followed by a large-scale expansion of production for export.

Siemens AG (Munich, Germany; new.siemens.com) is a technology partner for the project, and aims to use its Silyser electrolyzer technology, which is based on a proton exchange membrane (PEM), especially designed to handle wind and solar energy to produce H_2.

The project is the second massive renewable energy project in Western Australia, following the 15-GW wind and solar facility proposed for the Pilbara region, known as the Asian Renewable Energy Hub, and backed by CWP Renewables (Newcastle, Australia; www.cwprenewbles.com), Macquarie Group (Sydney, Australia; www.macquarie.com) and wind-turbine manufacturer Vestas (Aarhus, Denmark; www.vestas.com). This project represents about $30 billion in investment and has the potential to generate 50 terawatt-hours of electricity per year.

Findings suggest new design principle for water-splitting catalysts

Hydrogen derived from water and renewable electricity, rather than from natural gas, could offer abundant energy without carbon dioxide emissions if water-splitting processes could be scaled up effectively. But the best catalyst for the reaction — platinum — is scarce and expensive, which prevents widespread scaleup. New findings from researchers at Brown University (Providence, R.I.; www.brown.edu) suggest a new approach to designing catalysts that could avoid the dependence on platinum.

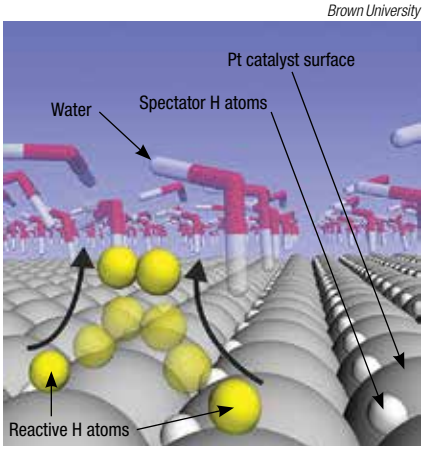
Current orthodoxy holds that Pt acts as an effective catalyst because the free energy of adsorption of hydrogen onto the catalyst surface is close to zero. The result being that H atoms are not bound too weakly (so that they don't initiate a reaction), but also not bound too strongly (so that they fail to complete the reaction and form H_2).

However, other materials with binding energies similar to platinum have catalyst activities that are orders of magnitude lower than those of Pt, suggesting that factors other than binding energy are at play. The Brown research team, led by engineering professor Andrew Peterson, created specialized computer simulations that suggested another mechanism for the metal's catalytic activity.

At high reaction rates, the hydrogen atoms with zero free energy don't actually participate in the water-splitting reaction. Those that do sit atop the Pt atoms, rather than within the lattice of the catalyst material and are bound more weakly to the catalyst surface (diagram).

Rather than using "just-right" binding energies as the main catalyst design principle, the researchers suggest that "designing catalysts that put hydrogen in this highly mobile and reactive state is the way to go." It's this "freedom of movement for hydrogen atoms on the surface that makes platinum so reactive," Peterson says.

Brown University



The researchers' insights could aid atomic-scale catalyst design that achieves activities similar to that of platinum.

devan.net) introduced two new bio-based products for textile applications: an antimicrobial (BI-OME Natural), which is used for odor control and as an anti-dust-mite product; and phase-change materials (PCMs; Tones of Cool Bio), which help control temperature conditions.

The active ingredients of BI-OME Natural are linseed oil and chrysanthemum (derived from the seeds of the flowers of the daisy).

Tones of Cool Bio is a patented cooling technology that stimulates the textile to dissipate redundant heat from the body and to instantly reduce the body temperature. The PCMs used in Tones of Cool Bio are derived from sustainable, natural sources, and are in the form of a crystalline wax or oily liquid (depending on temperature).

H_2O_2 PRODUCTION

Hydrogen peroxide is mainly produced industrially by the multi-step, energy-intensive anthraquinone process, which involves a hydrogenation step that requires an expensive palladium catalyst. Alternative methods have their own drawbacks, such as poor reactivity (direct synthesis from high-pressure H_2 and O_2 gases), or are not economically feasible due to the use of precious metal electrocatalysts (electrochemical reduction of O_2).

Now, researchers at the Center for Nanoparticle Research (led by director Taeghwan Hyeon and vice director Yung-Eun Sung) within the Institute for Basic Science (IBS; Daejeon, Korea; www.ibs.re.kr) in collaboration with professor Jong Suk Yoo at the University of Seoul, reported last month (in *Nature Materials*) an electrocatalyst that addresses all of the issues that trouble H_2O_2 production. This new catalyst comprises a Co-N_4 moiety incorporated in nitrogen-doped graphene — designated as Co_1-NG(O) — which exhibits a record-high electrocatalytic reactivity, producing up to eight times higher the amount of H_2O_2 that can be generated from rather expensive noble metal-based electrocatalysts (such as Pt, Au-Pd, Pt-Hg and so on). Using 1 kg of the new catalyst, it is possible to produce 341.2 kg of H_2O_2 within one day at room temperature and atmospheric pressure. The new catalysts are said to be exceptionally stable, without activity loss over 110 h of H_2O_2 production.

(Continues on p. 11)

MBRs improve the production of lignocellulosic-ethanol

Membrane bioreactors (MBRs) are widely used in wastewater treatment plants because they intensify the biotreatment process, reduce the number of processing stages, retain the biocatalyst and help remove the product from the suspended solids. In order to take advantage of these benefits, as well as to enable continuous production, membrane modules have been developed and tested for lignocellulosic-ethanol production by researchers at the Dept. of Resource Recovery, University of Borås (Sweden; www.hb.se), with cooperation and support from the Flemish Institute for Technological Research (VITO NV; Mol, Belgium; www.vito.be).

"Pressure-driven flat-sheet microfiltration immersed membrane bioreactors (iMBRs) were integrated into different processing stages of lignocellulosic ethanol production," according to Amir Mahboubi Soufiani, who defended his doctoral thesis last November. "The continuous fermentation iMBR set-up used for bioethanol production from wheat straw hydrolysate could operate at unconventionally high concentrations of suspended solids up to 20% w/v without significant deterioration of the filtration properties. This is ten times higher than the 0.8–2% solids loading operation of conventional iMBRs," he says. Also, the retention of high cell density in the iMBR enhanced the sugar consumption (total glucose and up 83% xylose), leading to high ethanol volumetric productivities of up to 4.6 g/L/h, says Mahboubi Soufiani.

A third-generation membrane module was also developed that combines the benefits of iMBRs and cell-encapsulation techniques into a so-called reverse membrane bioreactor (rMBR). This technique uses a concentration gradient, instead of pressure differential, as the driving force, and is useful for handling problems associated with the presence of inhibitors and sequentially fermented hexose and pentose saccharides in lignocellulosic fermentation, explains Mahboubi Soufiani. This membrane has been patented by VITO NV and the university.

Currently, another project is underway to develop MBR technology for the continuous production of volatile fatty acids (VFAs) found in anaerobic digestion of biogas plants.

Scaling up diamond growth for high-tech applications

A team of scientists in Kentucky are working to harness the unique material properties of diamonds — hardness, thermal conductivity, electrical resistivity and more — for advanced industrial applications, including biosensors and high-frequency and high-power devices. Kentucky Advanced Materials Manufacturing Co. (Louisville; www.kyammc.com), in collaboration with the University of Louisville (www.louisville.edu), operates a pilot plant where diamonds are grown from "seeds" in microwave-plasma reactors. The plant's three reactor lines have been producing diamonds for jewelry applications for over four months, but the team is currently working on scaling up production for industrial applications. "This work involves growing large single crystals of diamonds using seeds, expanding them and slicing them into wafers. If you really want to industrialize diamonds, you need a large single-crystal wafer," explains Mahendra Sunkara, professor of chemical engineering and director of the University of Louisville's Conn Center for Renewable Energy Research (www.conncenter.org).

The team has created seeds up to 11 × 11 mm in size, but there is still work to be done to commercialize these diamonds for the industrial space. "We are looking at ways of joining seeds together or growing larger areas on different substrates. We are also producing first-generation seeds, and transforming them into second generation seeds and removing defects," adds Sunkara. Ensuring polished surfaces that are free of defects is crucial, because any defects in the seed will be amplified when grown into a larger-scale stone.

The team is also working to optimize diamonds' integration with other materials. "If you can integrate diamonds with gallium nitride, this can enable high-voltage, high-frequency devices, including power devices that connect solar farms or wind farms into the grid, or next-generation telecommunications systems. Those are some of the commercial target areas we are looking at," says Sunkara. In the coming years, the pilot plant will pivot to these new applications by shifting to larger seeds and using different recipes for producing diamond materials tailor-made for high-tech devices.

A direct route to adipic acid esters

Adipate diesters are building blocks of polyamides and polyesters, and are used in plasticizers, perfumes, lubricants, solvents, various pharmaceutical active ingredients and, in terms of quantity, mainly for the production of nylon. Currently, adipate diesters are produced industrially by oxidizing a mixture of cyclohexanol and cyclohexanone with an excess of nitric acid, followed by esterification with the corresponding alcohols. This process requires special equipment due to the corrosive effect of the acid. In addition, stoichiometric amounts of the powerful greenhouse gas nitrous oxide are released.

Now, a "greener," simpler route to adipic acid is possible thanks to a new catalyst developed by a team of German scientists, led by professor Matthias Beller, director of the Leibniz Institute for Catalysis (Rostock; www.catalysis.de) and Robert Franke, head of hydroformylation research at Evonik Performance Materials GmbH (Essen Germany; www.evonik.com) and associate professor of chemistry at the Ruhr University Bochum (www.ruhr-uni-bochum.de). The scientists have succeeded in producing adipates (salts of adipic acid) by the direct dicarbonylation of 1,3-butadiene. Normally, this reaction forms many byproducts caused by secondary reactions, including telomerization, hydroalkoxylation and (co)polymerization.

The scientists have developed a palladium catalyst with a specially designed pyridyl-functionalized bisphosphine ligand (HeMaRaphos) that enables the highly selective and efficient double alkoxy carbonylation of 1,3-butadiene to adipic acid esters in one step. The key to success was the ligand design. The combination of a bidentate phosphine ligand with a basic pyridyl substituent on the phosphorus and a palladium precursor provides dialkyl adipates in the dicarbonylation of 1,3-butadiene in higher than 95% yield and with selectivity of 97% or more, as reported in a recent issue of *Science*.

The catalyst system can also be transferred to other dienes, paving the way for a revolutionary synthesis process for producing many fine chemicals, says Evonik. ■

AMORPHOUS MONOLAYER

Researchers from the National University of Singapore (NUS; www.nus.edu.sg) have synthesized the world's first one-atom-thick amorphous material. Previously thought to be impossible, the discovery of monolayer amorphous carbon (MAC) could finally settle a decades-old debate of exactly how atoms are arranged in amorphous solids, and open up potential applications, according to the researchers, who reported their findings in the January 8 issue of *Nature.*

Led by professor Barbaros Özyilmaz, head of the NUS Materials Science and Engineering, the NUS team grew the material and studied its properties and potential areas of application. Atomic resolution imaging was performed by the National Institute of Advanced Industrial Science and Technology (Japan) and Southern University of Science and Technology (China). Furthermore, theoretical simulations were carried out by Vanderbilt University. ❑

LINEUP

Look for more latest news on chemengonline.com

Plant Watch

Enterprise Products starts up isobutane dehydrogenation plant

January 13, 2020 — Enterprise Products Partners L.P. (Houston; www.enterpriseproducts.com) announced that its isobutane dehydrogenation (iBDH) plant in Mont Belvieu, Tex. began operations. The plant will ultimately have the capability to process approximately 25,000 barrels per day (bbl/d) of butane into nearly 1 billion lb/yr of isobutylene. The company is also constructing a propane dehydrogenation plant at the same complex and is on schedule for completion in the first half of 2023.

Eastman announces capacity expansion at Dresden plant

January 13, 2020 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) announced a capacity expansion at its Dresden, Germany manufacturing plant to support a new coating and laminating line. The expansion will supplement Eastman's assets in Martinsville, Virginia, and is expected to be online mid-2021.

Avantium to construct flagship FDCA plant in Delfzijl

January 9, 2020 — Avantium (Amsterdam, the Netherlands; www.avantium.com) has signed a letter of intent to locate its new flagship plant at Chemie Park Delfzijl, the Netherlands. The facility will produce 5,000 metric tons per year (m.t./yr) of plant-based furandicarboxylic acid (FDCA), which is a key building block for many chemicals and plastics. The plant is expected to reach completion in 2023.

Ineos Styrolution to build world-scale ABS plant in Ningbo

January 9, 2020 — Ineos Styrolution (Frankfurt am Main, Germany; www.ineos-styrolution.com) plans to build a world-scale acrylonitrile butadiene styrene (ABS) plant in Ningbo, China. The new production site will be adjacent to the recently acquired polystyrene plant in Ningbo. With a planned capacity of 600,000 m.t./yr, the plant will begin construction in 2020, with completion expected in 2023.

Showa Denko expands high-purity gases with new facilities in Shanghai and Taiwan

January 8, 2020 — Showa Denko K.K. (SDK; Tokyo, Japan; www.sdk.co.jp) will establish new facilities to produce high-purity nitrous oxide (N_2O) and high-purity octafluorocyclobutane (C_4F_8) gases in Shanghai. The new facilities will be designed to produce 1,000 m.t./yr of high-purity N_2O, as well as 600 m.t./yr of high-purity C_4F_8. Operations are expected to begin in the second half of 2021. Additionally, SDK will establish a new facility to produce 150 m.t./yr of high-purity C_4F_8 at its subsidiary in Taiwan. The startup of this plant is scheduled for the spring of 2020. The total investment for the new facilities in Shanghai and Taiwan is about ¥3 billion (around $273 million).

KBR announces first commercial license for its new PDH technology

January 6, 2020 — KBR (Houston; www.kbr.com) has won the first commercial contract for its K-PRO propane dehydrogenation (PDH) technology, which the company first introduced in January 2019. This new technology will be utilized for a 600,000-m.t./yr PDH plant in Asia. The planned PDH unit is expected to start up in 2023.

Sumitomo completes construction of two catalyst manufacturing lines in Chiba

January 2, 2020 — Sumitomo Chemical Corp. (Tokyo, Japan; www.sumitomo-chem.co.jp) has completed construction of two catalyst manufacturing lines in Chiba, Japan, to meet the demand of companies licensing its polypropylene (PP) and propylene oxide (PO) manufacturing technology, including S-OIL Corp., PTT Global Chemical Public Co. and Bharat Petroleum Corp.

Mergers & Acquisitions

Hexcel to merge with Woodward

January 13, 2020 — Woodward, Inc. (Fort Collins, Colo.; www.woodward.com) and Hexcel Corp. (Stamford, Conn.; www.hexcel.com) announced a definitive agreement to combine in an all-stock merger of equals. Upon completion of the merger, existing Woodward shareholders will own approximately 55% and existing Hexcel shareholders will own approximately 45% of the combined company, which will develop and manufacture advanced materials and control systems.

Victrex creates JV in China for new PEEK plant

January 13, 2020 — Victrex plc (Thornton Cleveleys, U.K.; www.victrex.com) created a joint venture (JV) with Yingkou Xingfu Chemical Co. to build and operate a new polyether ether ketone (PEEK) manufacturing facility in Liaoning, China. Victrex will hold a 75% interest in the JV. The new plant will be capable of producing up to 1,500 m.t./yr of PEEK. Commissioning of the facility is planned for early 2022, with Victrex's share of the overall investment expected to total £32 million.

Entegris acquires CMP slurry manufacturer Sinmat

January 13, 2020 — Entegris, Inc. (Billerica, Mass.; www.entegris.com) has acquired Sinmat, a Florida-based specialist in the design and production of chemical mechanical planarization (CMP) slurries used for polishing ultra-hard surface materials, including silicon carbide and gallium nitride. Entegris acquired Sinmat for approximately $75 million.

Milliken & Company acquires additives specialist Borchers Group

January 13, 2020 — Milliken & Company (Spartanburg, S.C.; www.milliken.com) signed an agreement to acquire Borchers Group Ltd. (Westlake, Ohio; www.borchers.com), a global specialty-chemicals company that provides high-performance additives and specialty catalysts for the coatings, inks and adhesives markets, including a range of cobalt-free driers, dispersants, rheology modifiers, wetting agents, polymerization catalysts and adhesion promoters.

Borealis to acquire NOVA ownership interest in Novealis JV

January 9, 2020 — Borealis AG (Vienna, Austria; www.borealisgroup.com) and NOVA Chemicals Corp. (Calgary, Alberta, Canada; www.novachem.com) have reached an agreement for Borealis to buy NOVA Chemicals' 50% ownership interest in Novealis Holdings LLC, the JV between affiliates of Borealis and NOVA Chemicals formed in 2018.

Ametek sells alloys business for $250 million

January 7, 2020 — Ametek Inc. (Berwyn, Pa.; www.ametek.com) announced that it has signed a definitive agreement for the sale of its Reading Alloys business to specialty materials company Kymera International. Reading Alloys has annual sales of approximately $160 million and is being sold in a transaction valued at $250 million. The company's products include master alloys, thermal barrier coatings and titanium powders.

Cabot to acquire China-based carbon nanotube manufacturer

January 6, 2020 — Cabot Corp. (Boston, Mass.; www.cabot-corp.com) agreed to purchase Shenzhen Sanshun Nano New Materials, Ltd. (SUSN), a carbon nanotube (CNT) producer in China, for approximately $115 million. SUSN commissioned a new CNT plant in China in November 2018. The parties expect to close the transaction in the second quarter of 2020. SUSN is the second-largest producer of CNTs in the world.

Huntsman finalizes sale of intermediates and surfactants units

January 6, 2020 — Huntsman Corp. (The Woodlands, Tex.; www.huntsman.com) completed the sale of its chemical intermediates businesses and its surfactants businesses to Indorama Ventures Public Ltd. (IVL; Bangkok, Thailand; www.indoramaventures.com) in a transaction valued at approximately $2 billion. ■

Mary Page Bailey

Pump Monitoring Meets the IIoT

Industrial internet of things (IIoT) technologies support online, continuous condition monitoring for pumps

Because pumps are often critical to process operation and safety, condition monitoring for pumps has long been a respected practice in the chemical process industries (CPI). However, the introduction of modern technologies and tools, developed with the industrial internet of things (IIoT) in mind, is changing the face of an already good thing and making it even better.

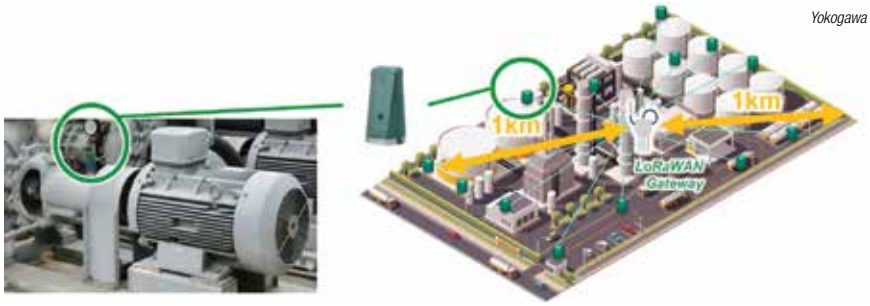


FIGURE 1. Yokogawa's Sushi Sensor, a wireless solution for IIoT, measures vibration and temperature, transmits data to the cloud or to on-premise infrastructure and assists with pump monitoring

Condition monitoring for pumps

Through the years, there have been several schools of thought on pump maintenance. For many years, pump maintenance was reactive in that pumps were run to failure. While this approach kept costs low at the onset, once a failure occurred, the loss could reach several thousand dollars in maintenance costs and even more in lost production and regulatory fines. Then along came preventive, or scheduled, maintenance, where maintenance activities were performed on pumps according to a schedule prescribed by the manufacturer or historical data. However, there was no guarantee that the maintenance was necessary or would prevent an unplanned failure between maintenance intervals. As a result, processors began to consider and practice proactive pump maintenance, which relies upon condition monitoring — usually vibration analysis and other measurements — to alert processors that maintenance was required based on actual information from the pump itself.

"Proactive maintenance, which is also known as predictive maintenance, appears more costly upfront, but the return on investment justifies the cost of condition monitoring, which is always less expensive than the loss of a critical asset," says Derek Lammel, an ISO Category 3 certified vibration analyst and reliability engineer with Dynapar (Gurnee, Ill.; www.dynapar.com). "Condition monitoring can include a vast array of techniques and monitoring, including vibration analysis, flow and temperature measurements, position of valves and more," he says. "Companies employing condition monitoring as a means to provide proactive/predictive maintenance tend to minimize downtime because it allows reaction before failure occurs, enabling not only prevention of failure, but preparation for necessary repairs — having parts and resources available — and scheduling of activities when it won't impact production."

There are additional benefits, as well. "What people don't realize is that one of the riskiest times for a pump, in terms of its operational life, is when you put it into service. There's more opportunity for failure — is it properly aligned, was oil added, are valves open, is there any downstream slag in the pipeline?" says Dan Kernan, executive director of aftermarket and technology with ITT Goulds Pumps (Seneca Falls, N.Y.; www.gouldspumps.com). "By taking pumps in and out of service for scheduled maintenance, you are introducing risk by exposing it to the possibility of instant mortality. Predictive maintenance, which is done when necessary versus a schedule, eliminates some of those risks."

Lammel points out another benefit. "While the money saved in decreasing unplanned downtime and production loss is significant, the number one benefit of using condition monitoring and predictive/proactive maintenance in pumping applications is safety of employees and protection of the environment," he says. Per Occupational Safety and Health Administration (OSHA; Washington, D.C.; www.

IIT Goulds Pumps

FIGURE 2. ITT Goulds Pumps' iAlert2 combines Bluetooth and sensor technology to provide continuous machine-health monitoring for early detection of machine failure

Dynapar

FIGURE 3. Dynapar's OnSite provides vibration analysis with cloud-based tools that provide 24/7 remote condition monitoring. Users can configure the system with application-specific triggers or thresholds, enabling the system to listen for vibrations, temperature or speed events once per minute

osha.gov) regulations, the CPI is required to prevent unwanted releases of hazardous chemicals in locations that could expose employees and others to serious hazards. "In these applications, condition monitoring becomes a necessity in order to avoid harming employees, the community or the environment, as well as avoiding regulatory fines, penalties and/or shutdown of the operation."

Condition monitoring and IIoT

Prior to the advent of technologies intended to support the blossoming IIoT, condition monitoring for pumps was done during periodic operator rounds, which involved a technician moving from asset to asset taking measurements with a handheld instrument, usually on a monthly basis. The data were transferred to a database, stored and reviewed to detect potential problems and allow predictive maintenance. However, due to currently available lower-cost sensors, hardware technologies that allow seamless transfer of data, the advent of inexpensive cloud computing and advanced analytical software, many processors are moving away from periodic condition monitoring to online, continuous condition-monitoring practices.

"Continuous, online condition monitoring in pumping applications is beneficial to processors because certain failure modes common to pumps, such as cavitation, can occur suddenly and degrade rapidly," says Lammel. "Within a month you could have a failure that was undetected during the last round. With continuous monitoring, the data can be taken, analyzed and reacted to daily, hourly or within minutes, depending on user needs. There's a huge benefit in being able to catch changing conditions early enough to prevent downtime."

He and other experts say IIoT technologies have enhanced condition monitoring. "Now sensor data can be collected continuously, sent to the cloud and analyzed from any computer, network or location around the world. Alerts can be sent to the appropriate manager or field tech via email or SMS message," explains Lammel. "But the real advantage lies in being able to, via cloud storage and computing, combine and analyze several data sources."

BJ Warren, IIoT sales manager for Cornell Pump (Clackamas, Ore.; www.cornellpump.com) explains: "Predictive maintenance is further enabled by the IIoT and data analytics because we can start to delve into not just vibration, but also other variables, such as temperature and flow, that come together to be analyzed and provide a bigger picture of pump health."

Lammel agrees: "On its own, information such as vibration, temperature or flow data might not reveal issues, but when these data sources are combined, potential issues may be recognized earlier. For example, the ability to correlate speed with vibration data might show that different vibration peaks line up with increases in running speed, which could indicate a potential issue. In applications that combine different sensor data, continuous monitoring and analysis help processors get to the root cause of the problems, as opposed to just sending an alarm."

Sepideh Rajaeirad, senior analytics engineer with Seeq (Seattle, Wash.; www.seeq.com), explains: "We have had all these data in the past, but the introduction of IIoT technologies, such as edge computing/cloud computing and tools for advanced analytics, enable the ability to manage and make useful these large volumes of available data with faster, greater computational power then ever before," she says. "This ability to bring advanced analytics to the fingertips of subject matter experts and engineers provides them with insight that empowers them to make better decisions about the equipment."

Juan Panama, business development manager with Emerson (Shakopee, Minn.; www.emerson.

com), adds: "When you start using IIoT technologies and advanced analytics to look at the matrix of fault conditions for each pump, including not just vibration, but measurements like suction pressure, discharge pressure, temperature and level, motor current, motor voltage and pump flow, they come together to provide a holistic view around the pump. That holistic insight is difficult to obtain by simply using a technician in the field once a month. Pervasive sensing and continuous monitoring make the collection process easier and advanced analytics allow users to make better decisions, prioritize maintenance and act accordingly so the pump doesn't fail. Simply put, IIoT technologies have enabled more effective, smarter and more actionable pump monitoring," says Panama.

Takayuki Sugizaki, manager of IA Products and Service Business with Yokogawa Electric Corp. (Tokyo, Japan; www.yokogawa.com) provides an example of how it all comes together: "For one customer, our Sushi Sensor — a wireless solution for IIoT that measures vibration and temperature and can transmit data to the cloud or to on-premise infrastructure — monitored the trend of pump acceleration for six months and detected abnormal signs. This is the first step of digital transformation," he says (Figure 1). "After noticing abnormalities, the Yokogawa team sent alerts to the users, enabling them to find breakage of balls in the bearings. This affirmed its ability to predict necessary maintenance. After this analysis, and as a check on our new technology, the Yokogawa team received raw historical data from the user and analyzed it using Yokogawa's artificial intelligence (AI) technology, which detected signs of abnormality three months prior to failure. With advanced decision making to supplement the dwindling number of experts by using machine learning and AI, maintenance plans can be efficiently carried out by combining equipment condition data with AI and machine learning."

Opto 22

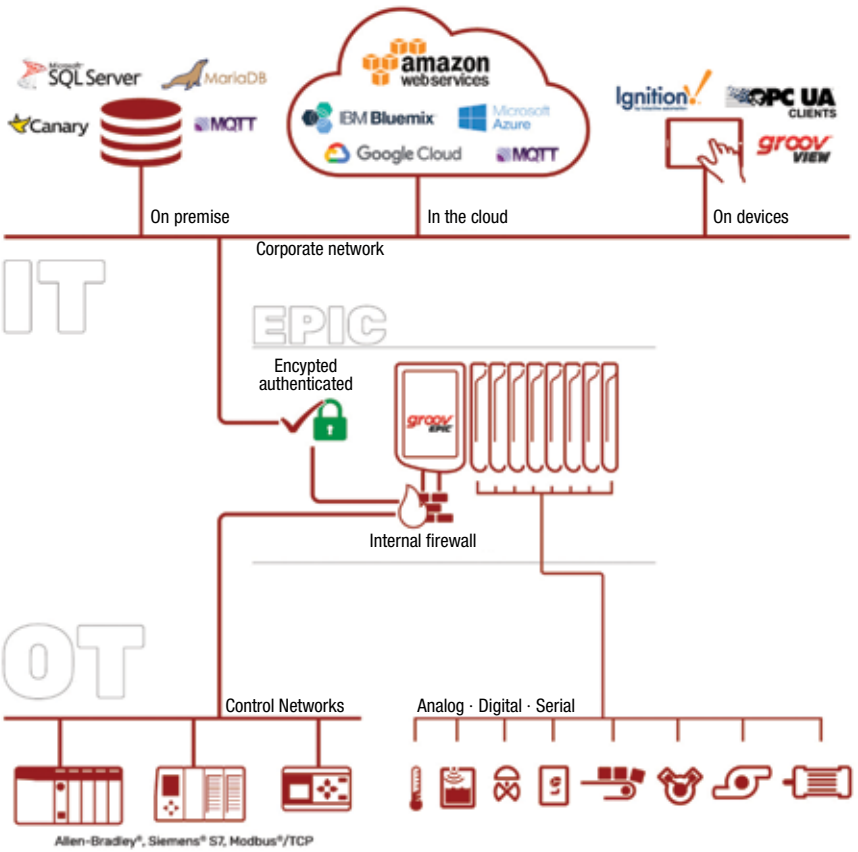


FIGURE 4. Opto 22's groov Epic combines technologies and tools for sensing, control, data processing and visualization and connectivity. It's a secure MQTT-enabled platform that can act as an industrial edge gateway for legacy PLCs and traditional or wireless devices and sensors

Pump monitoring via the IIoT

So, how does a processor advance and enhance pump monitoring? There are three main components. Sensors are used to collect data from the pumps. Users also need infrastructure for heavy computation, which includes cloud storage or edge computing to move and store the data. The third component is tools for advanced analytics. "This combination provides the necessary data along with a strong infrastructure that empowers users with the great computational power necessary to apply advanced analytics," says Seeq's Rajaeirad.

There are several approaches and various levels of involvement and investment that can be employed. The simplest are technologies and applications available from pump manufacturers. Condition-monitoring applications for pumps and rotating equipment are also available from companies that specialize in condition-monitoring technologies. Other avenues apply individual tools, such as devices for edge computing, that can be used with existing sensors to move information to its destination, and analytical software packages. Finally, there are holistic systems that provide all the sensing devices, transmission of the data and analytics in one package.

Specific applications

ITT Goulds Pumps recently introduced iAlert2, which combines Bluetooth and sensor technology into one package so users can monitor and diagnose equipment from a distance (Figure 2). It provides continuous machine health monitoring for early detection of machine failure via vibration, temperature and run-time monitoring, data logging with trend analysis, advanced vibration analysis tools, access to machine records and wireless syncing to mobile devices. "This type of Bluetooth condition-monitoring technology assists processors with making the move from

Emerson

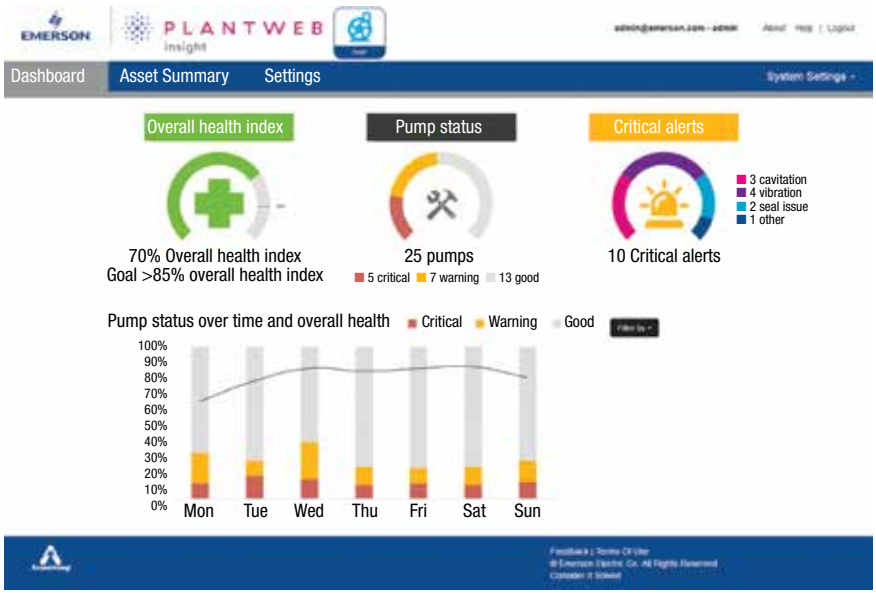


FIGURE 5. Plantweb Insight, a data analytics software program focused on different key assets in the facility, including pumps, can be used to run different analytics and provide actionable information

reactive to predictive maintenance," explains Kernan. "The focus here is on simplicity, speed and ease of use. To employ both condition monitoring and the IIoT, users need sensors that are economically feasible, as well as a way to economically get the data out of those sensors. The iAlert provides options to either simply provide a safer walk around by installing iAlert on the machine and collecting data via a smartphone or tablet without getting near the equipment or you can install a physical gateway that automatically picks up sensor data and brings it to the iAlert intelligence platform. In either case, the technology provides and moves the data needed to perform analytics based on a detailed picture to fully employ predictive maintenance."

Cornell Pump offers the Co-Pilot, which consists of hardware mounted to the pump, a cloud-based data interface and optional sensors. Every Co-Pilot subscription includes access to a portal that provides remote pump management either via a web browser or an app for smartphones. Through the portal, users can gain insight into several aspects of specific, pump-related information, running conditions and overall pump health. The technology also includes global positioning system (GPS), so users can track the pump's location.

"Co-Pilot monitors vibration and temperature of each pump via built-in sensors. In addition, we have the ability to pull in external inputs, so if the user has pressure transducers, flowmeters, level sensors or other sensors surrounding that pump, they can tie those into our module and push that data up to the servers, as well," says Warren. "This allows us to paint a picture of how that specific pump is operating, not just in terms of vibration and temperature, but exactly where the user is operating on the pump curve at any given time, while also viewing historical data. This means decisions can be made about whether the pump is running efficiently and in good health or whether to take corrective actions before the pump fails."

Also available are condition-monitoring technologies, such as Dynapar's OnSite, which provides vibration analysis with cloud-based tools that provide 24/7 remote condition monitoring (Figure 3). Users can configure the system with application-specific triggers or thresholds, enabling the system to listen for vibrations, temperature or speed events once per minute. When a threshold is met or exceeded, the system will respond by sending data to the cloud, where it is compared to user-created alarm levels. If alarm conditions are reached, the system notifies users via email or SMS message.

New technology towards IIoT

Specific applications are one step on the road to IIoT-based condition monitoring, but more and more technologies are available that can work with these and other applications to move processors even closer to a holistic view.

"While condition monitoring provides the level of equipment data needed to build useful performance models that enable accurate prediction, IIoT expansion has been slower than expected because of hazardous-environment requirements and barriers to interoperability and infrastructure scalability issues," says Josh Eastburn, director of technical marketing with Opto 22 (Temecula, Calif.; www.opto22.com). "An application like pump monitoring requires not only industrial-hardened sensing equipment, but also the ability to communicate larger amounts of data securely and efficiently, possibly from remote locations. The technologies that make up the traditional automation architecture consist of a heterogeneous mix of communications protocols and media communicating over disparate networks and applications, typically without inherent security. Extending these networks to bring in more data from far flung pump skids can become an expensive and risky proposition."

This has led to an evolution in the functions of industrial edge devices, which make it easier to create secure, reliable automation architectures, allowing such devices to knit together all the disparate systems and create a foundation of shared data with a layer of security that can be managed as one system. "And, on top of that foundation, an MQTT server, often called a broker, will solve the rest of the architectural puzzle. MQTT-enabled sensors communicate directly with the server, which in turn can make that data available to any number of applications," explains Eastburn. "Opto 22's groov Epic combines technologies and tools for sensing, control, data processing and visualization and connectivity. It's a secure MQTT-enabled platform that can act as an industrial edge gateway for legacy PLCs [programmable logic

controllers] and traditional or wireless devices and sensors. It can be relied upon to design scalable IT/OT infrastructure, connecting a variety of devices to on-premises and cloud-based systems" (Figure 4).

And, advanced analytics packages are the last part of the puzzle — once collected data are sent to the cloud, these analytical tools work their magic to analyze those data into actionable information. For instance, Seeq is in the space of advanced analytics, says Rajaeirad. "We connect the data source and enable advanced analytics, so engineers can rapidly investigate and share analyses from operations and manufacturing data sources to find insight."

Designed specifically for analyzing process data, the application works with time series data in historians or other storage platforms. "Most of the data coming from sensors are time series. Our applications provide the answers to challenges with advanced analytics that also enable engineers to use their expertise and knowledge of their process to solve problems and make decisions. Enabling engineers is key in IIoT applications and condition monitoring. Without their knowledge and expertise, we are missing a huge point, which is the real, live insight about the operation."

Holistic approach

While individual applications can be used and separate technologies can be combined to create an IIoT-driven, online, continuous condition monitoring system, there are also systems available that tie everything together in one package.

For example, Emerson offers sensors and transmitters for pervasive sensing and provision of the data that lays the foundation for condition monitoring. Once the raw data are acquired, they are sent to wirelessHART gateways and onto an analytics portfolio. "One example is Plantweb Insight, a data analytics software program focused on different key assets in the facility. One of these key assets is pumps, and Plantweb can be used to run different analytics and provide actionable information about them," says Brian Joe, global product manager, with Emerson (Figure 5). "We also have other analytics programs that can look at pump performance and tie it all together via collaboration tools that write work orders and distribute them to the right people at the right time. This is all part of Emerson's Plantweb Digital Ecosystem. We have the entire story to make the IIoT happen within these facilities."

No matter the approach, IIoT is without a doubt enhancing the capabilities of pump monitoring. "As technologies for the IIoT continue to expand and users begin to see the benefits, we will see changes in how condition monitoring is done and if they don't keep up with condition monitoring via the IIoT, they will be left behind," notes Dynapar's Lammel. ■

Joy LePree

Focus on Sensors

Omega Engineering

Fluid Components International

Larson Electronics

Wireless transmitters save on level sensor installation

Reduce the cost and complexity of installing a silo inventory-management system using this company's wireless-communication solutions. A simple point-to-point configuration eliminates the hassle and cost of running wires. Point-to-multipoint systems are easily scaled for more complex deployments using additional wireless units, base stations and wireless repeaters. Either setup can transmit up to a mile line-of-sight outdoors or 500 ft indoors. For easy point-to-point communication, the WR-30-TR wireless bridge uses two weatherproof units to transmit analog, Modbus or discrete data. For more complex applications, a custom point-to-multipoint system can be built using two or more WR-90-TR units in conjunction with a base station. Each base station accommodates up to 16 dual input/output expansion cards to transmit analog, digital or Modbus signals to a maximum of 32 WR-90-TR field units. — *BinMaster, Lincoln, Neb.*
www.binmaster.com

A new family of smart, wireless sensors/transmitters

The rugged long-range XW Series wireless sensor/transmitter system (photo) provides seamless connectivity across this company's catalog of sensors. The wireless devices are designed for demanding industrial applications indoors and harsh outdoor environments. The electronics are protected in a rugged weatherproof NEMA 4 (IP65)-rated housing and are simple to set up using a standard USB cable in conjunction with free SYNC configuration software. A wide variety of compatible probes and sensors mate quickly and easily with robust M12 connectors. The XW series provides options for compatibility with both digital and analog sensor types. The XW-ED accepts a wide variety of smart digital probes and accommodates pulse and process inputs. The XW-EDA model supports a wide range of thermocouples, RTDs, and precision process inputs. "Pro" versions feature two additional configurable discrete inputs/outputs, which enable true edge control capability. — *Omega Engineering, Norwalk, Conn.*
www.omega.com

Sensor design solves wet-gas flow measurement problems

The new optional Wet Gas (WG) MASSter Sensor (photo) delivers accurate, repeatable gas-flow measurement in the presence of moisture and condensation droplets. Available with the Model ST80 Series flowmeters, this new WG sensor configuration features a mechanical design that shunts moisture, condensation and water droplets away from the thermal flow sensor, thus maintaining an accurate gas-flow measurement while minimizing errors that could occur due to a cooling effect on the sensor. The WG MASSter Sensor option can be used in applications that have either moisture entrained in the gas or for protection against down-the-pipe rain in larger, vertical stacks. The ST80 Series flowmeters with the WG MASSter Sensor option are suitable for pipe diameters from 1 to 99 in. (25 to 2,500 mm) and air/gas temperatures up to 850°F (454°C). They have an accuracy of ±1% of reading, ±0.5% of full scale and repeatability of ±0.5% of reading with flowrates up to 1,000 ft^3/s (305 Nm^3/s) and 100:1 turndown. — *Fluid Components International, San Marcos, Calif.*
www.fluidcomponents.com

This ethanol sensor operates in explosion-proof zones

The EXP-SNR-TG-EC-ITS-ALG-E200 explosion-proof ethanol sensor (photo) is configured to detect ethanol vapors at concentrations from 0 to 200 parts per million (ppm), for use in Class I, Division 1 hazardous locations. The electrochemical sensor includes an internal data logger that stores measured gas values, which can be viewed on the LCD screen or downloaded using the interface. Operators have the ability to calibrate,

Note: For more information, circle the 3-digit number on p. 54, or use the website designation.

view data, set alarms and do other tasks with a magnetic tool, which eliminates the need to open the sensor enclosure. — *Larson Electronics LLC, Kemp, Tex.*
www.larsonelectronics.com

Avoid calibration inaccuracies with this calibrator

Many processing plants within the pharmaceutical and food industries feature a wide range of short sanitary sensors that cause problems during calibration because of their shape and size. Because of this, these sensors necessitate calibration within an oil bath, which often introduces further problems. To avoid these difficulties, this company offers a portable calibration kit for use with its JOFRA RTC-156 dry-block calibrator (photo). Customized inserts and a reference sensor were developed specifically for this application. This kit features inserts that protrude above the well, providing surface-to-surface contact between the sensor and the insert. A port in the kit allows users to position a flexible reference sensor at the same depth as the sanitary sensor tip for more accurate and consistent results. If the penetration depth doesn't allow for proper immersion, users can position the reference sensor from the bottom of the insert to the depth of the sanitary sensor. — *Ametek Sensors, Test & Calibration, Alleroed, Denmark*
www.ametekcalibration.com

Position sensors for hostile environments

High-temperature LVDT (linear variable differential transformer) position sensors (photo) operate in applications with extreme temperature environments where other position-sensing technologies, such as encoders, magnetostrictive sensors and potentiometers, cannot survive. With standard a.c.-operated LVDTs available with temperature ratings up to 400°F (204°C) and custom linear position sensors available with temperature ratings up to 1,000°F (538°C), the company offers sensors in a range of temperature ranges that offer the highest reliability in challenging applications, such as chemical processes (valve position at petrochemical plants), material testing chambers (specimen position monitoring), power plants (steam valve positioning), downhole oil drilling (cutter orientation, wellbore case profiling and wire and cable line tension measurement) and jet engines (valve positioning near engine cores). — *NewTek Sensor Solutions, Pennsauken, N.J.*
www.newteksensors.com

Non-contact displacement sensor for extreme conditions

This company's line of Extreme Environment high-precision displacement sensors and systems feature a rugged all-welded and hermetic construction. The sensors and systems are ideal for turbine-engine validation testing, and are also suitable for other applications that require high accuracy, high reliability and structural integrity, including nuclear reactors, steam and gas turbines, chemical processes and high-temperature processing. Three separate systems are available (photo), specifically designed for high-pressure, low-temperature and high-temperature conditions. The Extreme Environment sensors and systems work in operating temperatures ranging from –320 to 1,000°F (up to 1,200°F short term). Displacement systems withstand pressures up to 5,000 psi. Their dual-coil sensor design effectively minimizes temperature effects. — *Kaman Precision Measuring Products, Middletown, Conn.*
www.kamansensors.com

Sensors for low torque and high bandwidth measurements

The digital ORT 230/240 Series (photo) is a new optical rotary-torque sensor suitable for applications when the demand is for low torque or high bandwidth (or both), providing precise, dynamic measurement of rotary and static torque of less than 100 Nm and for bandwidths of up to 50 kHz. The ORT 230/240 devices replace the company's E200 ORT series, benefiting from all-new electronics that deliver significant gains in resolution, frequency response, reduced sensor-current consumption and faster digital data throughput, says the company. The ORT 240 enables users to connect up to 10 transducers via USB, and transducer-configuration software allows users to make changes to transducer variables. — *Sensor Technology Ltd., Wroxton, Banbury, U.K.*
www.sensors.co.uk ■

Gerald Ondrey

Ametek Sensors, Test & Calibration

NewTek Sensor Solutions

Kaman Precision Measuring Products

Sensor Technology

New Products

Block I/O devices with IP65/67 protection

Siemens

This company has launched a new generation of machine-level block I/O devices with the Simatic ET 200eco PN (photo). The new I/O family features IP65/67 degree of protection and includes five digital I/O devices, as well as an IO-Link master device, offering users a wide range of new functions. In their new industrial metal enclosure, the devices are reliably protected from ultraviolet (UV) radiation and harmful substances, even under adverse environmental conditions, making it possible to use the devices outside of factory buildings. The devices are supplied with power via an L-coded plug, resulting in a considerably higher current-carrying capacity. In turn, this enables longer cable routes in the field, and the supply and connection of more energy-intensive components (such as valve terminals) without the need for more supply cables. — *Siemens AG, Munich, Germany*

www.siemens.com

Sifters for sanitary and corrosive environments

Gericke USA

GS Series centrifugal sifters (photo) are manufactured in either 304 or 316 stainless steel for installation in sanitary and corrosive environments. The sifters are specified to condition granular and powdered products prior to entering production, to safely remove foreign matter from the product, or to separate the product into two streams based on particle size between 40 µm to 5 mm. GS Series sifters feature a rotating paddle assembly that harnesses centrifugal force to pass fine particles through a mesh screen and divert oversized particles to the discharge. All set within a sealed, dust-tight housing, the screen and basket may be safely accessed within the machine for 360-deg visual inspection and quickly removed for cleaning and fast changeovers with minimal downtime. The GS Series comprises four standard models, each available with screen mesh sizes from 100 to 4,000 µm, throughput rates up to 120 ton/h and a choice of surface finishes. — *Gericke USA, Somerset, N.J.*

www.gerickegroup.com

New self-priming pumps feature optional external flush

Vertiflo Pump

The Series 2100 self-priming centrifugal pump (photo) is well suited for handling solids and waste, due to its easy impeller access for clearing debris. The pump has an oversized, tapered bore and

a self-flushing seal chamber. It also has what is said to be the industry's first optional external flush, resulting in extended seal life. Series 2100 pumps can handle flow capacities up to 1,300 gal/min and heads up to 112 ft. The pumps are available in 3-, 4-. and 6-in. sizes. The Series 2100 is suitable for a wide range of applications, including: liquids entrained with solids, pulp-and-paper processing, mining, raw sewage, sludge, slurries and wastewater. — *Vertiflo Pump Co., Cincinnati, Ohio*
www.vertiflopump.com

An expanded analytics platform for infrastructure management

This company has added two new IIoT solutions to its Plantweb Insight data analytics platform (photo). The new Plantweb Insight Network Management application provides continuous, centralized monitoring of WirelessHART networks. This first-of-its-kind application provides a singular, consolidated view of the status of all wireless networks in a facility, with embedded expertise and guidance for advanced network management. A key feature of the Plantweb Insight Network Management application is a configurable mesh network diagram, which provides visualization of network design and connections, along with device-specific information. It also provides an exportable record of system log alerts, network details outlining conformance to network best practices and more. While the new network-management application provides a holistic look at wireless networks, the Plantweb Insight Power Module Management application drills down to the device level, allowing facilities to keep their wireless devices appropriately powered so that they can continuously transmit key monitoring data. — *Emerson, Austin, Tex.*
www.emerson.com


Emerson

New multifunctional temperature calibrator

The MC6-T is a multifunctional temperature calibrator and communication device that can provide accurate reference measurements and simulations for temperature, pressure and electrical signals, such as resistance, current, voltage, pulses and frequency, together with HART, Profibus PA and Foundation Fieldbus communicator. According to the manufacturer, the MC6-T can replace many individual devices, such as a temperature block, temperature calibrator, pressure calibrator, field communicator or datalogger. The device also offers the capability to calibrate short and flanged sanitary sensors, which is typically not possible with traditional temperature dry-blocks. The MC6-T is available in two different models: MC6-T150 for low-temperature applications and the MC6-T660 for higher-temperature calibrations. — *Beamex, Inc., Marietta, Ga.*
www.beamex.com/us
Mary Page Bailey and Gerald Ondrey

Solid-Liquid Separation Capacity in Centrifuges

Department Editor: Scott Jenkins

This one-page reference describes how to measure the capability of a given centrifuge to separate solids from a liquid phase.

G-force

The centrifugal force developed by a centrifuge is expressed as a multiple of the force of gravity. This force, known as the G-force, is proportional to the distance from the axis of rotation and the square of the rotational speed, as shown in Equation (1).

$$G = 39.48\, n^2\, r / g \qquad \textbf{(1)}$$

Where:
G is the G force
n is the rotational speed, revolutions per second (rev/s)
r is the distance from the axis of rotation, cm
g is acceleration due to gravity, which has a conventional standard value of 981 cm/s^2, but depends on altitude

Equation (1) indicates the primary parameters available to designers to obtain the desired G-force — the diameter and rotor rotational speed. The G-force is not uniform throughout the centrifuge. The force is smallest near the axis of rotation, and then increases linearly in the radial direction. Typical G-forces developed by several types of centrifuges vary widely, ranging from a low of 600 × g for the single-chamber bowl centrifuge, to as high as 1,000,000 for the ultracentrifuge (Table 1). Values at the high end are sufficient to remove macromolecules, such as nucleic acids.

TABLE 1. G-FORCES GENERATED BY VARIOUS TYPES OF CENTRIFUGES (× g, m^2/s)

Single-chamber bowl centrifuge	600 –1,200
Decanter centrifuge	2,000–5,000
Multichamber bowl centrifuge	5,000–9,000
Disk stack centrifuge	5,000–15,000
Laboratory bottle centrifuge	2,000–20,000
Tubular centrifuge	12,000–62,000
Ultracentrifuge	20,000–1,000,000

Sigma factor

While the G-force is an important characteristic of a centrifuge, it may not be a complete indicator of separation capability. This is because centrifuge performance is impacted not only by the applied force, but also by the area available for settled solids. That is, for a given applied G-force, a centrifuge with more settling area offers greater separation power.

A better measure of the separation capability of a centrifuge is its sigma factor, ∑, which is defined as the cross-sectional area of a gravity settling tank that would give the same separation performance. Values depend on centrifuge geometry and configuration (for instance, the size and number of settling surfaces), in addition to the G-force. For some types of centrifuges, equations for direct calculation of the sigma factor are given in engineering handbooks.

Typical sigma factors for several types of centrifuges are provided in Table 2. As with G-force, ∑ values vary widely, ranging from a low of 20 m^2 for the batch solid bowl, up to 120,000 m^2 for the disk-stack centrifuge. Although the decanter is highly versatile and widely used, as discussed below, its sigma factor is relatively low because of its relatively low settling area. Conversely, the disk stack centrifuge contains a large number of disks, providing substantial settling area, and in turn, a high sigma factor.

TABLE 2. SIGMA FACTORS FOR VARIOUS COMMERCIAL CENTRIFUGES

Batch solid bowl centrifuge	20 – 200 m^2
Decanter centrifuge	150 – 2,500 m^2
Tubular centrifuge	2,000 – 3,000 m^2
Disk stack centrifuge	400 – 120,000 m^2

Please note that the sigma factors shown in Table 2 are only approximations; because of complex flow patterns within the centrifuge, actual performance may deviate by as much as 50% from the given values.

Sigma factors can be employed to size a production-scale centrifuge using pilot data obtained with the same type of centrifuge, according to the relationship shown in Equation (2):

$$Q_2 = (Q_1\, \Sigma_2) / \Sigma_1 \qquad \textbf{(2)}$$

Where: Q is the flowrate and ∑ is the sigma factor

Subscripts 1 and 2 refer to pilot and production scale, respectively. Equation (2) says that if an optimized throughput of Q_1 is obtained with a pilot centrifuge having a sigma factor of Σ_1, then a production unit with a sigma factor of Σ_2 will be needed to obtain the desired production flowrate of Q_2. Equation 2 can also be used to determine if the desired throughput can be achieved with an existing centrifuge with a known value of Σ_2. That value and the pilot data are used to calculate Q_2, which is then compared to the desired value to see if the centrifuge is suitable. However, because of the approximate nature of sigma factors, results obtained using this approach should be regarded as no more than rough estimates.

Key parameters

Important parameters for centrifuge operations include the process objective (whether the solid is the valuable product or the liquid is valuable), the physical properties of the feed, the density difference between the solid material and the liquid phase, the particle size and shape and the viscosity of the liquid. The ease of separation increases with an increase in the density difference between the solids and the liquid, meaning less force is needed and a smaller centrifuge (or a centrifuge operated at a lower rotational speed) can be used to obtain a given throughput.

Smaller particles are more difficult to remove than larger ones, because in general, the sedimentation rate increases with the square of the particle diameter. The centrifuge design needs to be based on the smallest particle to be removed. However, not only is the particle size important, but also its shape. For example, flat, elongated particles tend to settle more slowly than spherical ones. In addition, solids tend to settle more slowly with increasing liquid viscosity, requiring a larger centrifuge or higher rotational speed to achieve the desired capacity. ■

Editor's note: Material in this column comes from Gabelman, A., Beyond Gravity: Centrifugal Separations in CPI Operations, *Chem. Eng.*, July 2016, pp. 52–59.

Nitrobenzene Production

By Intratec Solutions

Nitrobenzene is an important chemical intermediate. More than 95% of nitrobenzene is used in the production of aniline, which is largely used to manufacture isocyanates for polyurethane foams, plastics and dyes. The relative ease of aromatic nitration has contributed to the varied industrial applications of nitrobenzene derivatives.

The process

The process examined here (Figure 1) is similar to Noram's adiabatic benzene-nitration process, and consists of three major sections: benzene nitration, purification and vent treatment.

Benzene nitration. Benzene is preheated and fed to a plug-flow nitrator. Nitric acid (65 wt.% solution in water) is also preheated and mixed with fresh and recycled (re-concentrated) sulfuric acid before being fed into the reactor. In the nitrator, benzene reacts with nitric acid, producing nitrobenzene. The process operates with a stoichiometric excess of benzene to ensure complete nitric acid conversion in the nitrator. The reaction product is sent to a decanter, where crude nitrobenzene is separated from the spent sulfuric acid. Spent sulfuric acid recovered from separator is flash-concentrated under vacuum.

Purification. Water removed from spent acid is sent to a vacuum decanter. The organic condensate from the decanter is routed with crude nitrobenzene to a three-step washing train, where most of impurities are removed. The water generated in the wash step is treated with the aqueous condensate from the decanter in a column and discharged as waste. Product material exiting the washing train is sent to a steam stripper to recover the excess benzene, which remains in solution with the nitrobenzene up to this point in the process. Benzene is separated from water and recycled. Finally, the nitrobenzene product is separated from water and sent to an aniline plant.

Vent treatment. Vents generated along the process, after being combined, are sent to a scrubber. The scrubber uses a nitrobenzene slipstream to recover any benzene present in the vent stream. The bottom product is recycled to the washing train, while the overhead stream is sent to a packed bed unit to remove nitrogen oxides, forming a dilute nitric acid solution that is sent back to the nitrator.

Production pathways

Nitrobenzene is commercially manufactured by direct nitration of benzene using a mixture of nitric and sulfuric acids. The nitration plant can also be integrated upstream with a nitric acid production plant. In this case, the main raw materials are benzene and ammonia (which is converted to nitric acid via oxidation and then used in the nitration of benzene). Nitrobenzene production pathways are presented in Figure 2.

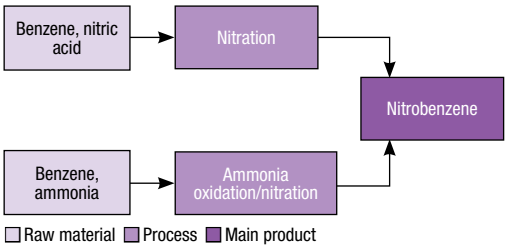


FIGURE 2. Two pathways to nitrobenzene are shown here

Economic performance

The total operating cost (including raw materials, utilities, fixed costs and depreciation costs) estimated to produce nitrobenzene was about $600 per ton of nitrobenzene in the first quarter of 2016. The analysis was based on a plant constructed in the U.S. with the capacity to produce 530,000 metric tons per year of nitrobenzene.

This column is based on "Nitrobenzene Production from Benzene – Cost Analysis," a report published by Intratec. It can be found at: www.intratec.us/analysis/nitrobenzene-production-cost. ■

Edited by Scott Jenkins

Editor's note: The content for this column is supplied by Intratec Solutions LLC (Houston; www.intratec.us) and edited by *Chemical Engineering*. The analyses and models presented are prepared on the basis of publicly available and non-confidential information. The content represents the opinions of Intratec only. More information about the methodology for preparing analysis can be found, along with terms of use, at www.intratec.us/che.

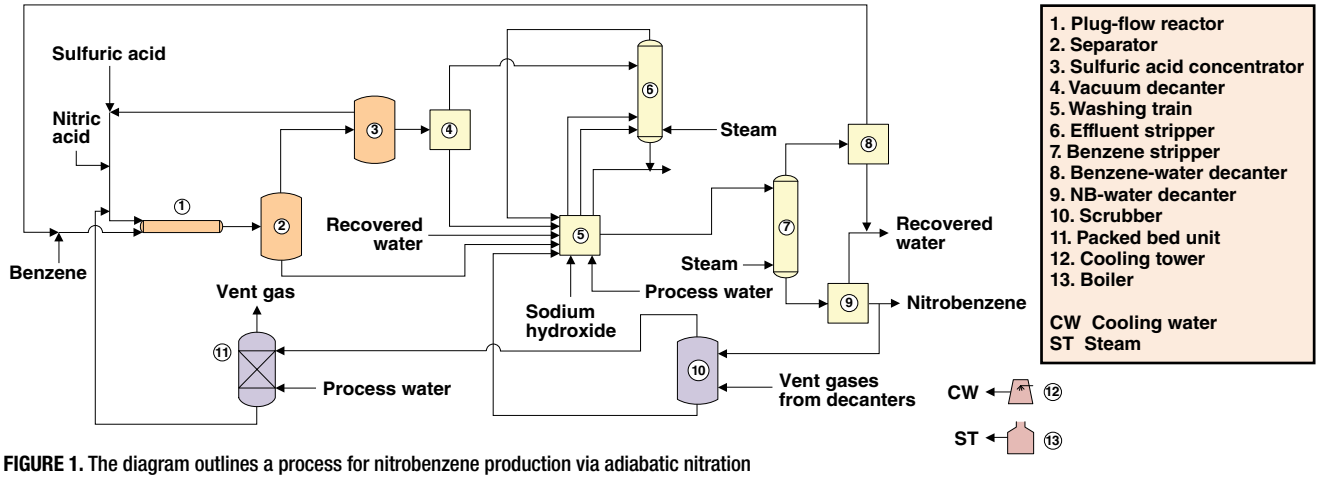


FIGURE 1. The diagram outlines a process for nitrobenzene production via adiabatic nitration

Part 1

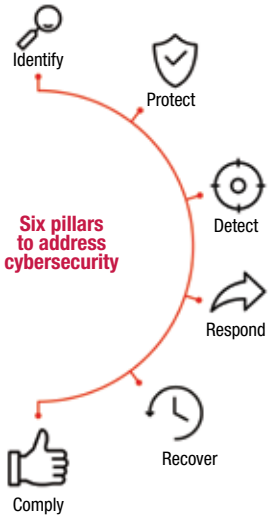
Elasticity for an Effective Cybersecurity Response

While no company wants to envision becoming the victim of a cyberattack, investing time upfront to craft an incident-response plan can provide a quicker path to recovery

Zied M. Ouertani
ABB

IN BRIEF

Cyberattacks are becoming a way of life — in both our personal, and increasingly, our business lives. The pages of newspapers and trade magazines are full of stories of breaches that have led to the disclosure of personal and financial information. While these attacks can have a devastating effect on the individuals concerned, they cannot be compared to the scope of potential damage caused by security breaches at industrial facilities. With all the media coverage and promptings from cybersecurity vendors, it is impossible not to be aware of the risks. If anything, significant fatigue is beginning to set in as some vendors use fear, uncertainty and doubt to sell their products and services.



Identify
An organization's commitment to align to baseline security requirements, and then routinely measure themselves against those baseline requirements.

Protect
The goal is to minimize unnecessary exposure to potential vulnerabilities

Detect
A proactive approach to threat and vulnerability management.

Respond
It is unlikely that all energy operators will eventually experience a security incident. The impact of that event is largely determined by the strength of a company's incident-response capabilities.

Recover
Energy operators must be able to back up and restore their systems to a near real-time position regardless of whether the event was caused by a cyberattack, human error or physical failures. The key to managing an incident is how effectively an organization is able to recover.

Comply
Regulatory compliance and training are essential.

FIGURE 1. This six-pillar approach to cybersecurity focuses not only on incident prevention, but also on crafting an effective response plan in the event that a cyberattack does occur

According to a survey commissioned by cybersecurity firm Kaspersky Lab (Woburn, Mass.; use.kasperky.com) that quizzed more than 300 professionals with decision-making power on operational-technology (OT) and industrial-control-system (ICS) cybersecurity, 77% of companies believe that cybersecurity is a significant priority [*1*]. A similar number believe they are likely to become a target of a cyberattack. Despite this raised awareness, only 23% said that they were compliant with minimal mandatory industry or government guidance and regulations around cybersecurity of industrial control systems.

In another report from Ponemon Institute LLC (Traverse City, Mich.; www.ponemon.org), respondents said around half of successful cyberattacks resulted in downtime of critical systems.

Attacks on industrial control systems can potentially cause vast amounts of damage, and in some of the worst cases, explosions. As cyberattacks become more sophisticated, an ICS in particular remains a key target. In the first quarter of 2019, industrial companies ranked second out of organizations most often hit by cyber-attackers globally [*2*].

Chemical operators know they need to manage cybersecurity risk and threats, but they face a number of challenges to do

this effectively. In order to master industrial cybersecurity challenges, chemical operators need to develop a robust strategy and put countermeasures into place (Figure 1). They also need to ensure sufficient funding for security programs to run smoothly.

Proliferation of cloud and edge

There are three main challenges when it comes to securing chemical facilities from cyberattacks. The first is remediating security risks in older systems. Next is developing reference architectures for greenfield sites. Finally come the challenges associated with the proliferation of cloud and edge technologies (Figure 2). Edge devices are those that control data transmission across network boundaries.

Recently, there has been a rapid rise in the use of edge devices and cloud computing, and we need to entirely understand what security means in this context. What controls do we need to implement around different data use cases for cloud and edge technologies? Leading operators in the sector are focusing on the reference architecture as reference use cases in how they would like those security controls designed. However, it is important to recognize that it is not particularly effective to have this reference built in as an afterthought — instead, it needs to be part of the initial system build.

CFATS

Unlike many other critical infrastructure sectors, in the U.S., the federal government regulates cybersecurity for the chemical process industries (CPI). Under the Chemical Facility Anti-Terrorism Standards (CFATS), chemical facilities must meet comprehensive cybersecurity requirements that address the protection of business networks and process control systems. See Part 2 of this Feature Report (p. 32) for more information on CFATs.

Beyond CFATS, the chemical sector has also been actively engaged with the federal government as the National Institute of Standards and Technology (NIST; Gaithersburg, MD; www.nist.gov) moves forward with implementing a cybersecurity framework in response to Executive Order 13650, Improving Chemical Facility Safety and Security, in response to the deadly explosion at a fertilizer distribution facility in West, Texas, which occurred in April 2013 [*3*].

This enforcement at a governmental level is great and enables chemical operators — regardless of size, degree of cybersecurity risk or cybersecurity sophistication — to apply the principles and best practices of risk management in improving the security and resilience of their critical infrastructure.

There is not a one-size-fits-all approach, however, in effectively managing cybersecurity risk. Operators will continue to have unique risks

FIGURE 2. The proliferation of cloud and edge connectivity presents new challenges in securing digital and physical assets

— different threats, different vulnerabilities and different risk tolerances — and as such, the impact of a cyber-incident is largely determined by the strength of a company's own incident-response program. Thorough planning and communicating what actions are to be taken and ensuring a coordinated response greatly reduces the potential negative impact.

A chain reaction

When CPI companies begin an investigation after suffering from a cyber-event or cyberattack, one of the first calls usually made is to their digital technology suppliers, asking them to test the system and help the business get back online.

There are significant dependencies put upon suppliers intrinsically linked to internal operations teams. Together, they need to work to answer a number of essential questions after an attack has taken place. For example, are they carrying out system backups frequently enough? Have they undertaken drills, so they know how to recover a system from the ground up? Are they capturing logs that are long enough to provide forensic analysis?

The breadth and depth of this partnership must be agreed upon in advance so that teams can come together seamlessly and quickly to manage damage and limit downtime after an attack.

There is also the outbound supply chain to consider. What is the effect for customers and what damage could limitations, albeit temporary, cause them? These are some of the nuances chemical operators need to understand and have mapped out and ready in the event of an incident.

FIGURE 3. Educating all personnel in their role and stake in cybersecurity-related matters is a critical pillar in maintaining secure facilities

Responding to a cyber-incident

The three foundations of effective cybersecurity plans are people, process and technology. Many organizational policies focus on the latter two factors, but people are just as critical to maintaining a robust security posture (Figure 3).

With these principles in mind, the pathway to overcoming a cyberattack on an industrial control system follows a multistep process of appraisal, understanding and action, which is detailed in the following sections.

Step 1. Establish communication and partnerships. First, begin by understanding the internal partnerships and relationships that are needed to achieve industry response resilience. The challenge arises because a cyber-incident could threaten any component, piece of equipment or process across an entire business. Establishing communication and complete visualizations of operations and how different elements partner or relate to one another is vital to success. As mentioned previously, these interactions are complex and can involve many pieces of the supply chain.

Step 2. Design incident-response drills. It is crucial to not overlook the importance of designing incident-response drills to expose potential gaps and friction points in the process. When it comes to responding to a cyber-event, all interactions, responsibilities and interdependencies are crucial. It cannot be emphasized enough how vital recovery drills and effective scenario playbooks are to foster understanding and compliance. For example, a drill could be that the team can run through specific scenarios.

Incident-response drilling is essential, because it not only helps understand potential scenarios, but it also improves the elasticity of a security team and its procedures. Can

they adapt to change well? Can they work well together? Does leadership understand how to act when there is a security event?

Gaining insight and knowledge into what is required, both from a procedural and a culture standpoint, is extremely beneficial. It is like the analogy of forcing water through a pipe — you want to know where the leaks are when you are carrying out drills, not when it is a real incident.

Step 3. Develop and track KPIs. Focused tracking of key performance indicators (KPIs) around incident responses leads to a better understanding of risk, investment needs and opportunities to improve. There can be a serious gap here with leadership understanding when it pertains to cybersecurity. It is commonly seen that the only time leaders hear about their security teams and the excellent work they do is when there is an incident, or when there is an issue around availability — then, it is rarely positive. These teams work ceaselessly to defend the plant and processes, to improve the overall recovery time, or improve on their drills. Responsibility for managing risk must start with leaders — board members and chief executives need to lead a top-down approach in developing a culture of cyber-resilience.

The ability to have a discussion of cybersecurity with leadership and to get them to build confidence in the subject is crucial. Leadership responses can also be critical in positioning how a company is perceived externally. This is an area with which leadership needs to get comfortable handling and managing competently.

Step 4. Assemble the team. Though reasonably simple, having strong incident-response policies and procedures in place, backed with reliable enforcement, cannot just be driven by a security team. These procedures need to be understood and followed by all relevant stakeholders in a company, from operations through to the legal and communications departments, to make sure that they are practical,

and that team members can implement them effectively.

Step 5. Create a playbook. This step is traditionally called operating models, but a better name might be incident-response playbooks. The key here is that these playbooks are living constructs, and they reflect the inputs of the stakeholders that would be engaged in an incident. Playbooks are the basis for action, and they give team members boundaries. More importantly, they allow flexibility to improve and work effectively, which is crucial because cybersecurity is not static.

Step 6. Consider stakeholders. Last but not least, remember relevant stakeholders. One thing to always emphasize is the importance of open communication. Many companies suffer from adverse press coverage around security events if they do not communicate transparently and in a timely manner about what is going on.

Having a strong communication plan in place helps customers and all impacted parties to be more comfortable in the event of a cyber-incident

While it might not help in immediately restoring operations, having robust communications engagement will certainly deliver longterm benefits. Having a strong communication plan in place helps customers and all impacted parties to be more comfortable in the event of a cyber-incident.

Right now, many operators are even employing agencies that specialize in security-incident-response communications, which can craft holding statements to inform and soothe the sentiments of all stakeholders. This transparent and upfront approach can be critical in impacting share price, goodwill and company perceptions.

Ensuring a resilient response

The vital element in all of this is building security elasticity into the chemical organization. Over the past ten years, we have heard a lot —some would say too much — about OT security. We have heard about minimum standards, about the do's and the don'ts. We have heard so much about this that there is now a reference to "basic cybersecurity hygiene." However, this phrase implies that many cybersecurity challenges might have been avoidable, had a higher level of diligence been applied. The flipside of this coin, in contrast, is providing resiliency in incident response.

While the focus to be "secure-by-design" is excellent and necessary, as an industry, we now have a unique opportunity to focus a bit more on incident response. By doing this, we can ensure that our resiliency lines up precisely with our enterprise risk-management principles.

The best way to mitigate cyber-risk or to recover quickly after an attack is to embed the principles of identification, protection, detection, response, recovery and compliance within organizational behavior and culture, and apply best-practice learnings from system design through to the decommissioning stages of critical process equipment.

It is vital to remember that even though it is challenging to find the time for both security and operations teams, any time spent upfront on incident response is going to help chemical operators be more resilient. Waiting until an incident occurs to learn about incident response is not recommended. Instead, the smartest CPI operators are preparing for tomorrow by investing today. This wiser decision will support their resiliency and performance in the longterm. ■

Edited by Mary Page Bailey

References

1. PAC on behalf of Kaspersky Lab, The State of (Global)Industrial Cybersecurity 2018; ics.kaspersky.com/the-state-of-industrial-cybersecurity-2018/.
2. Positive Technologies, Cybersecurity Threatscape Q1 2019, June 2019, www.ptsecurity.com/ww-en/analytics/cybersecurity-threatscape-2019-q1/.
3. U.S. Environmental Protection Agency, Executive Order on Improving Chemical Facility Safety and Security, August 1, 2013, www.epa.gov/rmp/executive-order-improving-chemical-facility-safety-and-security.

Author

Zied M. Ouertani is the global technology manager, Chemicals and Refining, Energy Industries at ABB (Phone: +49 6213811012; Email: mohamed-zied.ouertani@de.abb.com). Located in Mannheim, Germany, Ouertani joined ABB in 2012 and has served as the company's principal scientist in corporate research and as a business consultant for corporate strategy. He holds a PhD in information systems. He brings more than 10 years of global experience, and is skilled at connecting customer needs to value-added digital solutions. Prior to ABB, he worked at the University of Cambridge, U.K., as a postdoctoral researcher for the Cambridge Service Alliance, and as a business transformation consultant for IBM, BAE Systems and Caterpillar.

Part 2

Making Cybersecurity Training a Priority

All critical infrastructure segments are at risk for cyberattacks, but the unique integration of the chemical manufacturing sector into the global supply chain makes it an especially ripe target

Taeil Goh
OPSWAT

IN BRIEF

Defined by the U.S. Department of Homeland Security (DHS), critical infrastructure (CI) sectors are industries that are deemed so vital that their "incapacitation or destruction" would have debilitating effects on the country. We understand that critical infrastructure powers our homes, cleans the water we drink and provides the systems to communicate with family and friends, but, in reality, all critical infrastructure sectors are so interwoven that crippling just one sector could have debilitating effects that ripple across all sectors (Figure 1).

FIGURE 1. Critical infrastructure sectors are intrinsically linked through a global supply chain that depends on the raw materials manufactured by the CPI. This interconnectivity increases the reach of potential cyberattacks

For example, the chemical process industries (CPI) provide core raw materials to the energy, manufacturing and healthcare sectors; the energy sector fuels the government, defense and manufacturing sectors; while the information technology (IT) and communications sectors work to ensure that all of these sectors can seamlessly communicate and coordinate with one another.

Unfortunately, the potential to incapacitate one of these sectors — whether through physical threats or cyber action — is growing. Cybersecurity threats in particular are causing government officials to demand action, including former U.S. Secretary of Homeland Security Janet Napolitano, who called out cybersecurity as one of the top three threats that the DHS can and must confront [*1*]. In fact, according to a report from the World Economic Forum (Cologny, Switzerland, www.weforum.org), cyberattacks causing disruption to operations and critical infrastructure ranks among the top five global risks for 2019 [*2*].

Napolitano's comments should come as no surprise, as daily headlines now feature stories of yet another attack that has resulted in the loss of time, effort and revenue, as well as damaged brand reputation for the victim. The idea of attackers sitting behind a screen, collecting data, stealing information and gaining financially from their exploits is an alarming reality, but it is nothing compared to the wide-ranging impact an attack could have if one of these critical infrastructure sectors were to be successfully compromised.

While cyber-criminals have set their sights across the CI spectrum, they are increasingly targeting the chemical manufacturing sector because of its deep integration and connection to so many diverse industries. And yet, despite these potential threats, the chemical sector remains far too vulnerable to a wide range of advanced threats. To ensure continued prosperity, we must

FIGURE 2. Cyber-criminals are increasingly seeking out vulnerabilities in different critical infrastructure sectors that can be exploited to cause maximum damage

take immediate action in order to harden the chemical sector's security and resiliency, which starts by understanding the totality of the risk landscape.

A prologue to targeted attacks

Ten years ago, the world got its first taste of how a highly targeted industrial attack could wreak havoc on critical infrastructure with the disclosure of Stuxnet, a sophisticated malware worm that was unleashed inside an Iranian nuclear enrichment site, setting their nuclear aspirations back several years while demonstrating the potential vulnerability of all critical infrastructure assets.

Stuxnet was unique in a few key ways. For one, it was likely the handiwork of a nation-state actor and was designed specifically to target supervisory control and data acquisition (SCADA) systems, which are configured to control and monitor a variety of supervisory operations, such as temperature sensors and control valves. First-generation SCADA systems were designed as monolithic, standalone systems that were effectively isolated from other hardware and software resources. Today, third- and fourth-generation SCADA systems are networked and web-based, which make them easier to maintain and integrate with other systems, but this increased connectivity also opens doors into the network that previously did not exist.

Stuxnet was also noteworthy for what it did not do — if a designated target was not running a specific vendor's software, it would go dormant, allowing it to gain persistence on the network and evade detection until the right conditions were met. Since Stuxnet, other malware entities targeting industrial systems have emerged — including Duqu, Triton and Flame — suggesting that threat actors will continue to refine their industrial attack vectors.

Rising risk of attack in the CPI

As criminals seek high-value targets with perceived lax security controls where they might better exploit known vulnerabilities, they are increasingly targeting the chemical sector — either directly or indirectly via supply-chain attacks (Figure 2). Most recently, two major U.S. chemical companies were hit with a targeted attack in March 2019 involving the LockerGoga ransomware that caused potentially catastrophic disruptions [*3*]. It has been suspected that because the two chemical companies that were targeted were owned by the same investor group, that the group behind the attack might have compromised one via the other.

In July 2019, Reuters reported that several chemical compa-

FIGURE 3. To improve supply-chain cybersecurity, all parties should begin to adopt unified practices and encourage open communication and visibility

nies had been hit with a variation of the Winnti malware, which was designed for longterm data exfiltration and was suspected to have been perpetrated by a group possibly working for the Chinese government [*4*].

From nation-state threat actors seeking to gain insider knowledge on intellectual property to the various criminal syndicates who have deployed ransomware attacks on CI targets for financial gain, there is no shortage of motivations for criminals. The reality is that it is hard to pin down exactly what drives criminals to target chemical producers except for the common thread that the chemical sector is deeply interwoven throughout the economy. In fact, the chemical industry is responsible for contributing in excess of $226 billion to the U.S. gross domestic product (GDP), demonstrating the scale of the industry and its crucial role in delivering services and goods across multiple markets.

Recognizing this threat, the U.S. government has made it a priority to raise awareness of the potential risks to the chemical sector through the creation of the DHS Chemical Facility Anti-Terrorism Standards (CFATS) program. As a result, 4,023 high-risk facilities have undergone authorization inspections, 4,990 have undergone compliance inspections and 5,539 have had compliance-assistance visits. However, as the name of the program suggests, its charter is focused primarily on the threat of manmade disasters, which includes cyberattacks, but it mainly emphasizes physical acts of terrorism [*5*].

Despite the expanded focus on risk reduction, the threat of attacks targeting the CPI still remains, as criminals accelerate both the complexity and frequency of their attacks against vulnerabilities within the sector.

ICS vulnerabilities

It can be said that an industrial control system (ICS) is the frontal cortex of a mission-critical environment. According to a 2018 survey conducted by the Ponemon Institute, 90% of professionals in ICS and operational technology (OT) environments reported that their organizations had been negatively impacted by at least one cyberattack in the past two years [*6*]. This issue was heightened through the convergence between information technology (IT) and formerly isolated OT networks and devices coming online together, as well as the advancement of the industrial internet of things (IIoT). Compounding the issue, many chemical companies today have deployed IoT sensors and cloud-based software to improve operational efficiencies in petroleum refineries, manufacturing facilities and distribution centers, broadening their potential exposure to external threats.

While these technologies can enhance efficiencies and reduce costs, they have also embedded vulnerabilities, as the added nodes of connectivity increase the available attack surface. According to reporting by cybersecurity firm Kaspersky Lab (Woburn, Mass.; usa.kaspersky.com), nearly half of all industrial systems have recorded evidence that hackers have attempted some sort of malicious activity [*7*].

Supply-chain attacks on the rise

Another opportunity that attackers are exploiting is the interconnectivity of the chemical sector with the global supply chain. Everything from petrochemical manufacturers to pharmaceuticals to chemical distributors, use, manufacture, store and transport chemicals along a complex worldwide supply chain. But, unfortunately, every link in the supply chain creates new opportunities for infiltration.

Concerns for the security of the supply chain are nothing new. However, ensuring that supply-chain partners abide by industry-defined best practices can be especially challenging. Borderless supply chains lack unified cybersecurity rules and regulations with which vendors can comply. Compounding the issue, many suppliers rely on outdated controls and infrastructure systems that are too costly to update, and consequently become vulnerable to targeted attacks. This is precisely what happened in 2017 when the devastating WannaCry ransomware wormed its way across the globe via older, unpatched versions of Microsoft's Server Message Block (SMB) networking protocol [*8*]. In one

study on supply-chain risk, 71% of the organizations surveyed believe they do not hold external suppliers to the same security and risk standards as their own [*9*]. In short, any vulnerabilities in your supply chain are also your own vulnerabilities, which is why a sound supply-management strategy — one that provides broad visibility across the supply chain and a "Zero Trust" approach to all layers of the ICS and enterprise network — is a requirement to secure a modern interconnected enterprise environment (Figure 3).

Training and awareness mitigate risks

It is easy to conflate the function of training and the concept of awareness, as both contribute to the end goal of improving an organization's overall security preparedness. However, it is worth distinguishing between the two. When we talk about "awareness" in the context of cybersecurity, it is imperative that an organization's senior management team does not simply just "buy into" it as part of their annual tactical planning exercise. Rather, it should be showcased as a guiding principle and positioned as a core pillar among management's key strategic priorities. While training should be infused across various constituents at every level of the enterprise, effective cybersecurity practices have the greatest impact when the executive leadership team shows that they have truly invested in creating a lasting culture of cybersecurity excellence.

This is especially important to recognize, given that attacks are not coming just from external emails and devices, but from internal sources as well, such as careless contractors, remote workers connecting from unsecured connections or even from a seemingly benign USB device.

There are many resources for chemical companies seeking to improve their cybersecurity posture. The DHS published a Chemical Sector Cybersecurity Framework Implementation Guide, and the American Chemistry Council (ACC; Washington, D.C.; www.americanchemistry.com) also offers resources and news updates about cybersecurity in the industry [*10*, *11*].

But the best security practices often come down to building discipline in both training and awareness. Kaspersky surveyed 282 industrial companies across the globe, nearly half of which were in the oil, gas or chemical industry, and found that 48% had plans to invest in more training. However, training is not a one-off event that can be checked off — it must instead be continuous. In fact, the report stated that many security managers noted that employees fell back into their "old, dangerous patterns of behavior" in six to nine months after completing a security awareness training course.

Chemical companies can no longer simply go through the basic motions and treat cybersecurity as an afterthought. Simply maintaining the rudimentary antivirus technologies and basic awareness is not enough to maintain control and ensure security. All employees — be they executives, engineers or accountants — must develop a deeper appreciation of the fact that any inter-

action with technology can open a door to a potential cyberattack.

Organizations must educate all employees and stakeholders that no matter their role, every person plays an important part in protecting mission-critical infrastructure. The following are several proactive steps chemical companies can take to improve their security posture and mitigate the growing risks of cyberattack:

- Conduct an internal cybersecurity audit to define a baseline from which to measure future progress and evaluate where knowledge gaps exist across all layers of the organization
- Prioritize practical, hands-on cybersecurity workforce training instead of just relying on concepts and theories, which can be difficult to comprehend and internalize. Just as you might prepare for a hazardous-material incident, you should likewise schedule simulated cybersecurity incident-response drills
- Establish the proper incentives, training, processes, procedures and performance management to ingrain the cultural changes and mindset needed
- Invest in training chemical engineering professionals in the right processes and technologies that improve cybersecurity across all levels of the organization
- Lead by example by having all executives and managers across departments take cybersecurity training courses to become knowledgeable in the risks, and to better understand how to communicate that information to everyone in their respective departments

Embracing a prevention mindset

So much emphasis of late has been placed on implementing strong detection capabilities. While this is an important facet of building a resilient security posture in general, it represents just a single component. It is imperative that every stakeholder across an organization also appreciates the equally significant role that usability, automation and prevention play in keeping a network safe. Emphasizing this mindset of prevention can help to foster a culture of accountability.

If a process is not user-friendly, personnel will all too often sacrifice security for the sake of productivity. Security leaders need to think as much about the usability of a given solu-

tion as they do about its core capabilities. Automating manual processes, such as network access controls and entitlement policies, can also go a long way toward avoiding nightmare scenarios of ex-employees gone rogue. Instilling a prevention mindset across your organization is just as much about people and processes as it is about the technologies and tools.

Protecting chemical facilities and operations against cyberattacks is a multi-pronged and continuous effort that requires organizations to have zero trust in their networks, files, devices and users. We must establish stronger protections, better incident-response plans, and security protocols that are not just resilient but also user-friendly.

This calls for ultimately changing the way everyone in the organization thinks about cybersecurity. The success of CI cybersecurity will rely on the steps taken by the workforce to mitigate the risks, and the conceit that humans should no longer be a last line of defense, but rather one of the first. The question is not whether you can afford to train every stakeholder in cybersecurity but whether you can afford to not train them. ■

Edited by Mary Page Bailey

References

1. Miller, M., Former Homeland Security secretaries call for action to address cybersecurity threats, *The Hill*, September 9, 2019.
2. World Economic Forum, The Global Risks Report 2019, 14th Ed., www.weforum.org/docs/wef_global_risks_report_2019.pdf.
3. Kovacs, E., Major U.S. chemical firms hit by cyberattack, *Security Week*, March 25, 2019.
4. Schuetze, A., BASF, Siemens, Henkel, Roche target of cyber attacks, *Reuters*, July 24, 2019.
5. U.S. Dept. of Homeland Security, Chemical Facility Anti-Terrorism Standards, www.dhs.gov/cisa/chemical-facility-anti-terrorism-standards
6. Tenable, Inc. and the Ponemon Institute, Cybersecurity in Operational Technology: Seven Insights You Need to Know, March 2019, lookbook.tenable.com/ponemonotreport/ponemon-OT-report
7. Kaspersky Lab, Threat Landscape for Industrial Automation Systems in H2 2018, March 27, 2019.
8. Kerner, S.M., WannaCry Ransomware Attack Hits Victims With Microsoft SMB Exploit, *eWeek*, May 12, 2017.
9. Bradley, T., Supply Chain Attacks Increase As Cybercriminals Focus On Exploiting Weak Links, *Forbes*, August 1, 2018.
10. U.S. Dept. of Homeland Security, Chemical Sector Cybersecurity Framework Implementation Guidance, 2015, www.dhs.gov/sites/default/files/publications/chemical-cybersecurity-framework-implementation-guide-2015-508.pdf.
11. American Chemistry Council, Cybersecurity and the Chemical Industry, October 2018, www.americanchemistry.com/policy/security/cybersecurity-october-2018-update.pdf.
12. ARC Advisory Group and Kasperky Lab, The State of Industrial Cybersecurity, July 2019, ics.kaspersky.com/media/2019_kaspersky_arc_ics_report.pdf.

Author

Taeil Goh is chief technology officer at OPSWAT (398 Kansas Street, San Francisco, CA 94103; Phone: 1-415-590-7300; Email: mediarelations@opswat.com). He has over 12 years of software engineering experience primarily in cybersecurity, delivering enterprise products to high-security industries, such as government, military, critical infrastructure and finance. His main focus is on leading the engineering team, but he is also in charge of IT infrastructure, business analytics, information security and cloud operations. His current cybersecurity focus is on building content disarm and reconstruction (CDR) and static analysis. He holds a B.S. in computer science from San Francisco State University.

Sustaining Effective Process Safety Programs

The elements needed for excellence in a process safety program are known, but achieving top-level process safety performance requires sustained effort and focus

James A. Klein
ABSG Consulting Inc.
(ABS Group)

IN BRIEF

Efforts to achieve excellent process-safety performance at chemical process industries (CPI) facilities are nothing new [*1*]. Experience shows that sustained excellent process safety performance is difficult, but not impossible, with the appropriate effort and resources. Although the CPI collectively possess the tools and knowledge for excellence in process safety, putting those into practice in all areas and at all times is difficult.

FIGURE 1. Sustained attention to process safety reduces the risk of disaster [*1*]

For most companies, achieving sustained positive results in process safety requires continuous focus and dedication. Sometimes a single mistake or equipment failure can lead to catastrophic results. Humans make mistakes and equipment can fail at any time, but many mistakes can be prevented, or their impact anticipated and safeguarded against. Similarly, equipment can be designed appropriately and effectively maintained, and the impact of failures can be anticipated and safeguarded against.

Excellent process safety performance requires continuous effort to implement, sustain and improve effective process-safety programs [*2*]. Guidance on the design and implementation of process safety programs has been available for many years [*3*], and in theory, most companies now have the technical knowledge and capabilities to safely identify and manage process hazards and risks. After all, process safety regulations have been in effect for over 25 years, and industry guidance and resources are widely available. In the early 1990s, Trevor Kletz [*4*] expressed that "new" accidents rarely occur; rather, the same types of accidents are repeated and therefore, should be preventable. More recently, Dennis Hendershot [*5*] similarly stated that "We know how to improve process safety performance . . . We need to actually do what we already know how to do, we need to do it well, and we need to do it everywhere and all of the time."

Yet despite this recognition, process safety performance concerns in the CPI unfortunately remain too common: serious and near-miss process incidents still occur too frequently due to ineffective process-safety programs or to the lack of recognition that a process safety program is needed. Serious

process safety incidents can lead to (1) fatalities and serious injuries, (2) catastrophic property damage, (3) significant environmental harm, (4) critical business disruption, (5) business reputational damage, and, in some cases, (6) negative community impacts. For example, a petroleum refinery explosion [*6*] resulted in 15 fatalities, 180 injuries, and major facility damage (Figure 1). Serious incidents and frequent near misses highlight significant performance problems and the ongoing need to achieve better process-safety performance, despite the industry's emphasis on incident prevention and continuous improvement efforts. This article discusses the requirements for sustaining effective process-safety programs to help achieve excellent process-safety performance.

TABLE 1. DRIVING FORCES FOR IMPROVING PROCESS SAFETY PERFORMANCE (ADAPTED FROM REF. 2)

- Near-miss and incident learning, including significant incidents internally or externally, as well as trends
- Poor or degrading leading and lagging process safety metrics, including audits
- Costs associated with poor performance (for example, lost production, repair costs, poor quality)
- New regulations and industry consensus standards and guidance
- New technology, including new hazards, as well as new applications
- Benchmarking with other companies
- Corporate restructuring, acquisitions and mergers
- Stakeholder relations (for example, communities, stockholders, employees and regulators)

TABLE 2. POTENTIAL CAUSES OF POOR PROCESS SAFETY PERFORMANCE (ADAPTED FROM REF. 2)

- Weak safety culture or leadership, or both
- Lack of senior leadership operational or safety experience, focus and commitment
- Compliance-based mentality rather than risk-based mentality
- Poor awareness, interpretation, or implementation of regulations and industry standards and guidance
- Poor hazard recognition/identification
- Poor process safety system design with inadequate risk assessment/management
- Poor operational discipline
- Cost/staffing/resource pressures
- Poor management of mergers and acquisitions
- Lack of experienced, knowledgeable management, technical and safety personnel
- Poorly designed feedback and measurement systems
- Complacency, or no sense of vulnerability resulting from past performance

Defining safety performance

The primary objectives of effective process-safety programs are to identify, evaluate and manage process hazards to help achieve excellent performance and ensure safe processes and facilities. But how should performance be defined? A basic definition of the term is as follows: "excellent performance prevents serious injuries and incidents." However, there are two potential problems with this definition. First, injury and incident statistics may be mixed with personal safety statistics (such as lost-workday cases) that may not provide a clear view of process safety performance. For example, subsequent investigation [*7*] following the refinery explosion in Figure 1 found that "reliance on injury rates significantly hindered … the perception of process risk." Second, injury and incident statistics are lagging metrics, representing events that have already occurred, rather than helping to identify problems before they can lead to more serious injuries and incidents (that is, leading metrics). Since serious injuries and incidents are hopefully infrequent, these indicators do not provide true measurement of how a process safety program is performing. The question is: are process safety systems working the way they should be on a day-to-day basis, or are there problems that may be leading to higher risks? And how would facility personnel know?

A better definition of performance relates to executing process-safety program requirements and systems with the intent of achieving program goals and objectives. Program goals should include the following: (1) how to prevent serious injuries and incidents related to process activities and (2) other leading and lagging indicators to measure the functionality and effectiveness of process-safety program activities to provide early warning of possible problems. Just as medical professionals measure vital signs, such as blood pressure and cholesterol levels, for early warning of potential health problems, accountable facility personnel should establish, monitor and respond to appropriate goals and metrics for process safety performance. For example, failing to document and assess changes to process equipment or to conduct equipment tests and inspections on the required schedules can greatly increase the risk of process-related injuries and incidents. Meaningful process-safety program goals with appropriate leading and lagging metrics, as well as management review of system performance, must be established to obtain a clearer view of process safety performance. How to achieve this is discussed here. While excellent performance can be demonstrated using lagging metrics, ultimately, excellent future performance can typically only be pursued using appropriate process-safety goals and leading metrics. Some important driving forces for achieving excellent process-safety performance are listed in Table 1, while potential causes of poor process-safety performance are listed in Table 2.

Current performance level

The key questions associated with process safety performance include the following:

- What is the current level of performance (high, average, or poor)?
- Is performance likely to get better, stay about the same, or get worse?

The answers to these questions

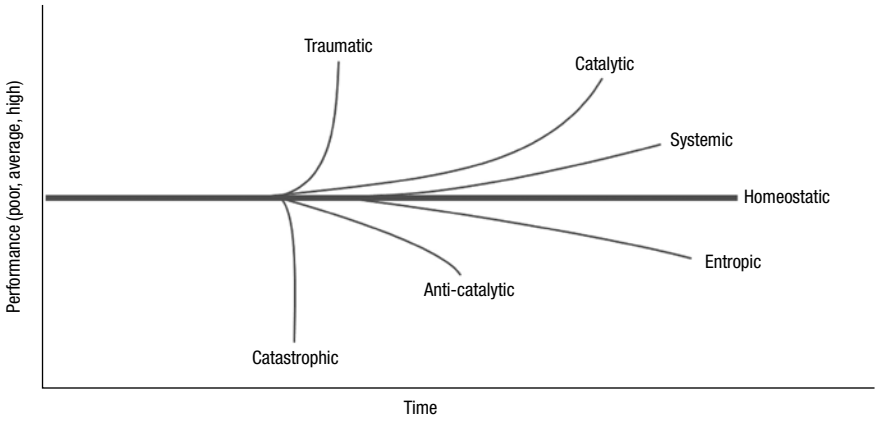


FIGURE 2. A facility's process safety performance over time can follow several different pathway scenarios

are obviously very specific to company or facility process safety goals based on (1) the particular process hazards and risks that may be present and (2) management priorities.

While assessing current performance seems straightforward, serious process-safety incidents are (hopefully) rare, and therefore performance is typically assessed in terms of conformance to process safety system requirements. But systems and expectations differ, and what is considered excellent performance at one company may not be at another, based on the goals and leading and lagging metrics that have been established. Also, companies may believe they have excellent performance, but the reality could be different when performance is assessed relative to industry standards and regulatory expectations. Both internal and external measurements should be considered when evaluating process safety performance. Facilities must, at a minimum, be aware of industry standards and best practices for comparison, and should benchmark operating results with other facilities and companies whenever possible.

The second question is more difficult. Several possible pathways or scenarios are shown in Figure 2. The *y* axis measures performance, where the current status can be generally categorized as high, average or poor. The current status is important because if a company already has excellent performance, it should mainly desire to maintain that high level. If a company has poor performance, it should set goals and provide resources for improvement. From the current status, several performance scenarios are possible:

Entropic. The entropic scenario is characterized by a slow degradation of performance. This is most common where continued attention to process safety performance is not maintained, and often results from either (1) complacency (for example, the absence of recent significant incidents leads to overconfidence that the process safety performance must be adequate), (2) lack of awareness of degradation (for example, no leading metrics or inadequate audits), or (3) competing priorities (such as financial pressures) that prevent appropriate focus on process safety performance. Without continued attention, any system, including a process safety system, will degrade over time as training and human performance expectations lag, equipment continues to age, and other distractions appear. Performance may continue along the entropic path until an event, such as a safety incident or audit, triggers a change of focus.

Homeostatic and systematic. These scenarios reflect continued goal setting to maintain and/or improve performance. Generally, process safety performance is likely to already be good, so the intent is to continue to provide resources to appropriately manage process risks. If performance is not already strong, then these scenarios may indicate insufficient management attention or resources to substantially improve performance until an event again triggers a change in priority for process safety. These scenarios are the most common performance targets for many companies.

Catalytic and anti-catalytic. These scenarios represent triggering events that either lead to rapid improvement or rapid degradation of process safety performance. Typical trigger events may include (1) a near-miss event that raises awareness of possible issues, (2) a change of leadership, such as a new plant manager with a different priority level for safety, (3) an acquisition or merger, especially where there are significant differences in corporate safety culture between the companies, (4) financial considerations due to a change in the overall economy or company cost control, (5) a regulatory change or inspection, (6) internal audits, inspections, or visits by managers that either question or confirm performance, and (7) lawsuits or other legal considerations.

Traumatic and catastrophic. These scenarios represent significant, rapid performance changes typically resulting from serious process incidents at a facility, within the same company, or in a related industry. If a serious incident occurs at the facility, obviously performance will drop immediately, and the disruption and distractions caused by the incident may lead to continued performance issues or even perhaps closure of the facility. If the serious incident occurs at another facility in the company or industry, it may serve as a wake-up call to motivate management to focus immediately on providing resources to improve process safety programs.

Consideration of these two questions — What is our current performance? and What will it be in the future? — is essential for achieving desired performance levels on both absolute (internal) and relative (external) criteria. Achieving excellent performance, of course, does not simply happen. It must be the result of management support of effective process-safety programs, setting annual program goals, and constant measurement and review of performance through appropriate feedback systems. A model of important factors that impact performance is discussed in the next section.

Achieving excellence

While all aspects of effective process-safety programs are ultimately important, the performance model [*2, 8*] shown in Figure 3 provides principal program activities that impact performance and indicates how they interact [*2*]. The key elements of this model are discussed below, with one or more possible actions that companies or facilities can take to help improve performance for each aspect.

Process-safety regulations and industry standards. Companies must be aware of regulatory requirements and industry best practices. In addition, effective implementation of programs to comply with industry codes and standards (often referred to as "recognized and generally accepted good engineering practices" [RAGAGEPs]), such as consensus standards issued by the American Petroleum Institute, helps ensure equipment is properly designed and maintained. Lack of knowledge of regulations, best practices, and RAGAGEPs will seriously reduce the effectiveness of process safety programs. Knowledge of external information and activities is essential for (1) leveraging organizational capabilities in process safety and (2) ensuring, among other things, proper equipment design and maintenance. The Center for Chemical Process Safety (CCPS), for example, has provided comprehensive guidance

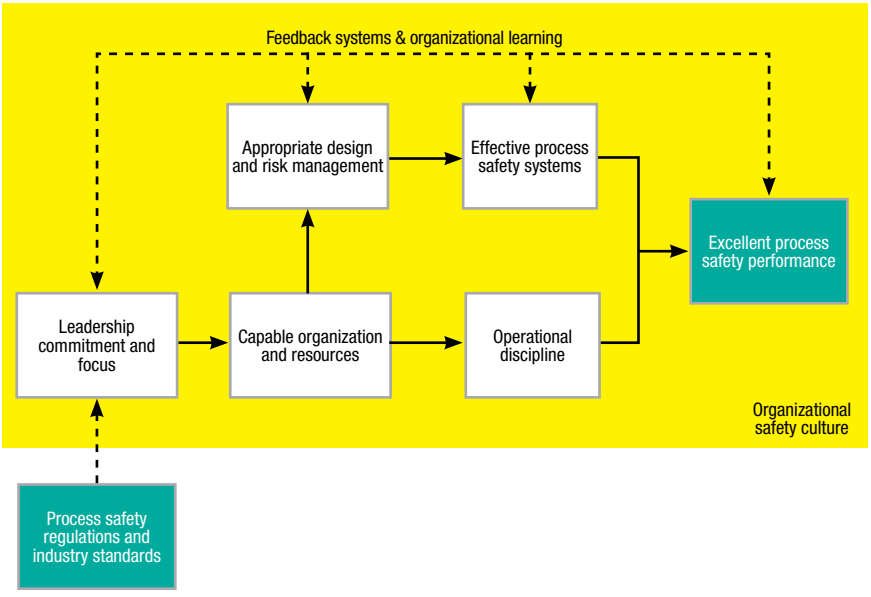


FIGURE 3. The diagram shows a model for process safety performance (adapted from Refs. 2 and 8)

TABLE 3. POSSIBLE ACTIONS FOR IMPROVING PROCESS SAFETY PERFORMANCE

1. Develop systems to ensure proper awareness, access and use of external process safety regulations and guidance
2. Periodically conduct safety culture assessments
3. Develop strategies to maintain a sense of vulnerability in personnel at all levels to help prevent complacency
4. Set appropriate, actionable and measurable process safety improvement goals annually
5. Ensure that appropriate process safety training is provided to all leadership as part of specific job roles and career advancement criteria
6. Review training strategies to support the implementation and performance of effective process-safety programs
7. Implement an organizational change process to evaluate organizational capabilities and manage personnel changes
8. Ensure process safety information that serves as the basis for process design (for instance, hazard information, process design basis, equipment design basis) has been properly compiled and is being maintained
9. Review current risk-management practices to evaluate whether or not hazard evaluations are being properly conducted during all stages of the process lifecycle (initial design to decommissioning)
10. Ensure appropriate leading and lagging metrics are being monitored to review process safety system performance
11. Identify operational discipline (OD) improvement opportunities based on implementing an OD program or conducting additional OD evaluations as part of an existing OD program
12. Develop a process safety learning plan

on risk-based process safety programs [*3*] and continues to develop new guidance based on industry best practices. Exposure to process safety literature through selected conferences and journals can also help keep process safety professionals current on new industry developments and practices. Part of organizational learning, discussed below, is to maintain an active external focus to enhance internal activities.

Possible action: Develop systems to ensure proper awareness, access, and use of external process safety regulations and guidance.

Organizational safety culture. The effectiveness of process safety programs and the ability to achieve excellent performance are strongly influenced by the safety culture. Differences in safety culture, often due to conflicting priorities, such as financial or production considerations, can have dramatic effects on safety performance. A poor safety culture, for example, may be able to achieve excellent performance in the short term, but is unlikely to sustain excellent performance over the long term. A good definition of safety culture is [*2*] "The normal way things are done at a facility, company, or organization, reflected expected organizational values, beliefs, and behaviors, that set the priority, commitment, and resource levels for safety programs and performance." Characteristics that describe the essential features of safety cultures have been defined [*3, 9*] and can be used to evaluate strengths and opportunities for improvement. As part of the safety culture, a sense of vulnerability should be maintained to help prevent complacency issues, especially when performance has been strong for a long time. Failing to maintain a sense of vulnerability can directly lead to a mistaken belief that success is routine rather than an outcome that requires continued focus and diligence [*10*]. This is the "entropic" performance scenario shown in Figure 2.

Possible actions: (1) Periodically conduct safety culture assessments. (2) Develop strategies to maintain a sense of vulnerability in personnel at all levels to help prevent complacency.

Leadership commitment and focus. Leadership at a company or facility is both influenced by the safety culture (for example, in setting daily priorities for safety versus production) and is also able to influence the culture (strengthening or weakening the culture over time). As discussed earlier, a change in leadership such as a new plant manager can lead to catalytic or anti-catalytic changes in process safety performance. Leadership necessarily encompasses all levels of management, from a company's board of directors to first-line supervision [*7*]. If a shift supervisor is making decisions contrary to guidance from higher levels of management, such as completing certain work tasks in an unsafe manner, then leadership credibility is challenged and the safety culture can degrade. Leadership commitment and focus on process safety are critical for ensuring that resources are provided to help build a capable organization, in terms of financial, personnel and time considerations. Process-safety program policies, goals, metrics, and accountabilities must be established with appropriate resources provided to support excellent performance. Direct leadership involvement in process-safety activities is also essential for building trust and securing employee engagement through visibility and consistent action.

Possible actions: (1) Set appropriate, actionable and measurable process safety improvement goals annually. (2) Ensure that appropriate process safety training is provided to all leadership as part of specific job roles and career advancement criteria.

Capable organization and resources. Company leaders must provide purposeful and sufficient resources for implementing and sustaining effective process-safety programs that support safe, high-quality, and reliable operations. This includes developing internally trained and capable process-safety professionals and others with expertise and knowledge of process operations, process safety regulations and RAGAGEPs to help ensure that process goals can be met. Since it is increasingly difficult for everyone to know everything about all technical areas, appropriate policies and guidance should be documented, training conducted, and networking and mentoring opportunities provided, especially for new or less experienced personnel. In some cases, it is often more effective to involve specialty resources, such as consulting services, for (1) designing effective process safety systems, (2) conducting process safety audits, and (3) assisting with risk management. The decision to develop in-house capabilities versus using specialist consultants and contractors is often based on the risk of the processes that are

operated by the company or facility, and other factors, such as company size and resources. Ultimately, process safety must become part of everyone's job in terms of ensuring that process-safety program goals and requirements are met. A well-defined training strategy should therefore be developed and implemented with refresher training at appropriate intervals to help (1) ensure awareness and understanding of process hazards that may be present and (2) ensure that process safety program requirements for managing these hazards are being met.

Possible actions: (1) Review training strategies to support effective process safety program implementation and performance. (2) Implement an organizational change process to evaluate organizational capabilities and manage personnel changes.

Appropriate design and risk management. Well-designed processes are the starting point for safe and reliable operations and for achieving excellent process safety performance. Process design must generate the desired product of course, but must also be based on identifying, evaluating and managing process hazards and risks. Where possible, process hazards should be eliminated using inherently safer technology approaches [*11*]. Remaining process hazards must be evaluated using appropriate hazard-evaluation methodologies to help ensure that process hazards are identified and the consequences of administrative and engineering controls have been evaluated. This includes providing safeguards, typically using multiple layers of protection [*2, 3*]. These evaluations are also used to ensure that process safety systems are designed and implemented as part of effective process safety programs to continually manage process safety activities and performance.

Possible actions: (1) Ensure process safety information that serves as the basis for process design (for example, hazard information, process design basis, equipment design basis) has been properly compiled and is being maintained. (2) Review current risk-management practices to evaluate if hazard evaluations are being properly conducted during all stages of the process lifecycle (for example, initial design to decommissioning).

Effective process safety systems. Process safety systems provide the detailed requirements of the process safety program to help ensure that (1) process hazards have been identified and evaluated before being first introduced into the workplace and (2) process risks are successfully controlled at all times as facility personnel complete their daily work activities. Process safety systems must be designed appropriately based on process hazards and risks that are present, applicable regulatory requirements, and best practice industry guidance. Various approaches have been proposed, ranging from eight management systems [*2*] to 20 risk-based elements [*3*]. OSHA (Occupational Safety and Health Administration) process safety management in the U.S. has 14 elements. Core process safety requirements are typically present in these elements, such as operating procedures, training, mechanical integrity, incident investigation and management of change. Proper functioning of these process-safety systems is essential for achieving excellent process safety performance, such that qualified and trained resources should be assigned to lead and monitor individual systems/elements, and specific metrics should be provided to monitor whether or not system requirements are being met. Many leading metrics are associated with proper functioning of these systems, which provide early warning of both current and future performance problems.

Possible action: Ensure appropriate leading and lagging metrics are being monitored to review process safety system performance.

Operational discipline (OD). Process safety systems only work as intended if personnel are actually following them; even highly trained people occasionally make mistakes. The reality is that human error should be anticipated, and appropriate systems and safeguards should be provided to make sure errors do not lead

to serious injuries and other consequences, especially if work tasks include higher-risk activities involving significant process hazards. Operational discipline is used to describe human behavior in following required systems and procedures correctly, every time, to consistently achieve safer and more reliable operations. Developing an OD program [*2, 12*] intended to support day-to-day awareness and commitment by all company personnel can help (1) minimize the potential for human error, (2) ensure process safety program requirements are rigorously followed, and (3) support excellent process safety performance. An OD program focuses on both organizational and personal OD to (1) help company or facility management develop the programs and work environment to support strong operational discipline and (2) provide resources for supporting OD improvement efforts. Personal OD programs are based on ensuring personnel at all levels have the knowledge, commitment, and awareness to complete their individual work activities correctly and safely every time.

Possible action: Identify OD improvement opportunities based on implementing an OD program or conducting additional OD evaluations as part of an existing OD program.

Feedback systems and organizational learning. Methods to monitor process-safety program effectiveness using both leading and lagging metrics are essential for achieving high performance [*2, 3*]. Without appropriate program feedback, warning signs of problems may be missed and learning opportunities for improving performance can be lost. Ensuring that the correct factors are measured and evaluated, based on process-safety program goals, provides information on the current performance level (poor, average, high) and trend direction (getting better or worse). Metrics by themselves are of little use unless they are acted upon, by identifying strengths and weaknesses and initiating specific improvement opportunities. Learning from experience is a common process-safety theme, and the use of organizational learning approaches to collect, analyze, share and retain critical process-safety information helps promote sensitivity to operations, a sense of vulnerability, and knowledge of past problems and successes [*2*]. Developing a process safety learning plan, based on learning goals, competency needs, information collection, and retention of knowledge can strengthen process safety programs and performance over time.

Possible action: Develop a process safety learning plan.

The possible actions discussed for improving process safety performance are summarized in Table 3. Many additional actions are possible, of course, based on specific facility goals, current performance, and identified improvement opportunities.

The reality is that human error should be anticipated and appropriate systems and safeguards should be provided to make sure errors do not lead to serious injuries and other consequences . . .

Concluding remarks

Are you happy with your process safety performance? What is the level of current performance relative to company expectations and industry standards? Will performance be better in the future? What specific approaches are being taken to make sure performance remains excellent or improves? Sustained excellent process safety performance is possible, but requires sustained commitment and resources to implement and improve effective process safety programs. Past success will not ensure future success, as competing priorities and other challenges will always be present. The technical knowledge and capabilities to implement and maintain robust process-safety programs and achieve high levels of performance are readily available, based on process safety regulations, industry guidance, and resources such as RAGAGEPs. The actions discussed here for helping to improve process safety performance are important, but ultimately deciding to set appropriate performance goals and evaluate specific facility or company opportunities for improving performance will increase the likelihood of process safety success. ■

Edited by Scott Jenkins

References

1. Klein, J.A., Two Centuries of Process Safety at DuPont, *Process Safety Progress*, vol. 28, pp. 114–123, 2009.
2. Klein, J.A. and B. K. Vaughen, "Process Safety: Key Concepts and Practical Approaches," CRC Press, 2017.
3. Center for Chemical Process Safety, "Guidelines for Risk-Based Process Safety," John Wiley & Sons, 2007.
4. Kletz, T., "Lessons From Disaster: How Organizations Have No Memory and Accidents Recur," Gulf Professional Publishing, 1993.
5. Hendershot, D.C., Process Safety Management — You Can't Get It Right Without a Good Safety Culture, *Process Safety Progress*, vol. 31, pp. 2–5, 2012.
6. U.S. Chemical Safety Board, "Refinery Explosion and Fire," Report No. 2005-04-I-TX, 2007.
7. "The Report of the BP U.S. Refineries Independent Safety Review Panel," 2007.
8. Klein, J.A. and J.R. Thompson, Improving Process Safety Performance, paper at Global Congress on Process Safety, Austin, Texas, 2015.
9. Center for Chemical Process Safety, "Essential Practices for Developing, Strengthening and Implementing Process Safety Culture," John Wiley & Sons, 2018.
10. Klein, J.A. and S. Dharmavaram, Improving the Performance of Established PSM Programs, *Process Safety Progress*, vol. 31, pp. 261–265, 2012.
11. Center for Chemical Process Safety, "Inherently Safer Chemical Processes: A Life Cycle Approach," Second Edition, John Wiley & Sons, 2009.
12. Klein, J.A. and E. M. Francisco, Focus on Personal Operational Discipline to Get Work Done Right, *Process Safety Progress*, vol. 31, pp. 100–104, 2012.

Author

James A. Klein, CCSPC, CSPA has over 39 years of experience in process safety, engineering, and research. He joined ABSG Consulting Inc. (ABS Group, 1701 City Plaza Drive, Spring, TX 77389; Email: jklein@absconsulting.com; Website: www.abs-group.com) in 2013 as a senior process safety consultant. Prior to that, he was process safety management co-lead for North America operations at DuPont. He is the co-author of "Process Safety: Key Concepts and Practical Approaches," published by CRC Press, and has developed over 50 publications, conference presentations, and university talks. He holds a B.S. degree in chemical engineering from the Massachusetts Institute of Technology (MIT), an M.S. degree in chemical engineering from Drexel University, and an M.S. degree in management of technology from the University of Minnesota.

Taking Advantage of Improvements in Level Measurement Technology

Level measurement technologies have become more versatile, robust and accurate thanks to recent developments. Differential pressure and radar level measurement provide examples

Lydia Miller
Emerson Automation Solutions

Level measurement applications within the chemical and petrochemical industries can be extremely challenging. Level instruments must provide repeatable, reliable and accurate measurement of hazardous materials over wide temperature and pressure ranges, and with complicating factors, such as steam, dust, foam, turbulence and condensation.

Solving the challenges of measuring the levels of fluids and solids in chemical processing applications is as old as the industry itself. Traditional methods, such as sight glasses and mechanical float switches or differential pressure (DP) level systems with wet- or dry-leg impulse piping, have all been used extensively and are still around today. But they can cause maintenance and reliability headaches, so many are getting replaced or augmented by more sophisticated methods.

DP level systems are reliable when applied properly, and well understood, so they continue to be commonly used. Advances in technology have solved many of the difficulties caused by traditional impulse-piping based systems. Radar is another option for easy and reliable level measurement that has also seen many advancements in technology to broaden overall capabilities. DP level and radar instruments are a mainstay with producers today because they can protect people, plants and products. This article looks at ways in which DP level and radar have advanced in recent years to deliver reliable performance for critical level measurements.

FIGURE 1. Differential pressure (DP) has been a practical level measuring technique for a century or more, but it is still being improved

Making DP more robust

Using a DP reading to determine liquid depth is a proven and reliable practice (Figure 1). Because of this, DP level continues to be one of the most common methods used to make level measurements. Internal tank structures, active agitation and corrosive or viscous processes that may cause challenges for alternative level technologies are ideal applications for DP level technology, which delivers a repeatable, stable and accurate measurement provided it is installed correctly and product density characteristics are understood.

DP challenges. But using DP to measure fluid levels is not without its challenges. Most problems relate to the necessity of mounting the head space pressure tap some distance above the tank bottom, and then connecting it to a DP transmitter using impulse lines. Since those impulse lines are connected directly to the process, they are often a source of headaches for any kind of DP application, because they can plug from accumulated debris, fill with the wrong product (gas in liquid lines and vice versa), and are subject to freezing and other environmental effects.

Remote seal systems. Remote diaphragm seal systems that use capillary tubes are one solution to some of the DP level challenges. A capillary tube is small-diameter, oil-filled tube that is provided as part of a DP level remote-seal system. It connects the remote diaphragm seals back to the pressure transmitter, which eliminates the need for impulse piping. This solves the main problems associated with plugged impulse lines — condensation in a dry leg or evaporation in a wet — but it introduces new trade-offs.

Balanced systems. There are two ways to implement remote-seal capillary tube systems. One creates a balanced system using two capillaries that are even in length on both the high and low side to keep temperature effects from creating errors between the two readings. Unfortunately, with balanced systems, the difference in the height between the

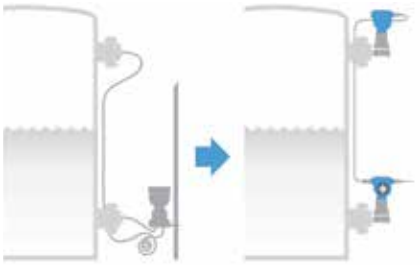


FIGURE 2. An electronic remote sensor system avoids problems with impulse piping or long capillaries by replacing them with a wired electrical connection

two measurements creates its own error. Also, having lots of extra capillary tubing, which often ends up coiled up by the transmitter, adds unnecessary cost.

Tuned assemblies. It was because of the drawbacks associated with balanced systems that the tuned assembly system was introduced. With this approach, the high-pressure side has a DP transmitter directly connected to the remote seal at the process connection and a single length of capillary tubing connected to the remote seal on the low-pressure side at the top of the tank. This creates an asymmetrical design that minimizes the overall fill-fluid volume within the system and allows the temperature effects from a vertical installation of capillary tubing to be compensated in the transmitter's calculations. This reduces overall system errors and improves response time when compared to a balanced system. Tuned assemblies, however, do have limitations. The longer the length required for the low-pressure capillary tube to reach the top of the tank, the greater the error associated with it. Therefore, for tall vessels, another approach is needed.

Electronic remote sensor. The newest technology for DP level measurement is an electronic remote sensor (ERS) system (Figure 2). An ERS system replaces the capillary tube connection to the top of the tank with a remote sensor connected electrically. This allows the head-space pressure measurement to be sent digitally, eliminating the problematic impulse lines and capillary tubes. While this ERS technique may sound like an obvious solution, it needs to be implemented correctly to make sure other errors are not introduced. It is critical to have special signal processing between the two transmitters, so they are working in synch to take readings simultaneously and provide a single DP output that avoids errors caused by changing level or pressure. If instead two independent readings are taken and used to make a calculation in the distributed control system (DCS), this creates the added cost of requiring two connections back to the host. Still, other errors can creep in that compromise the accuracy of the DP measurement.

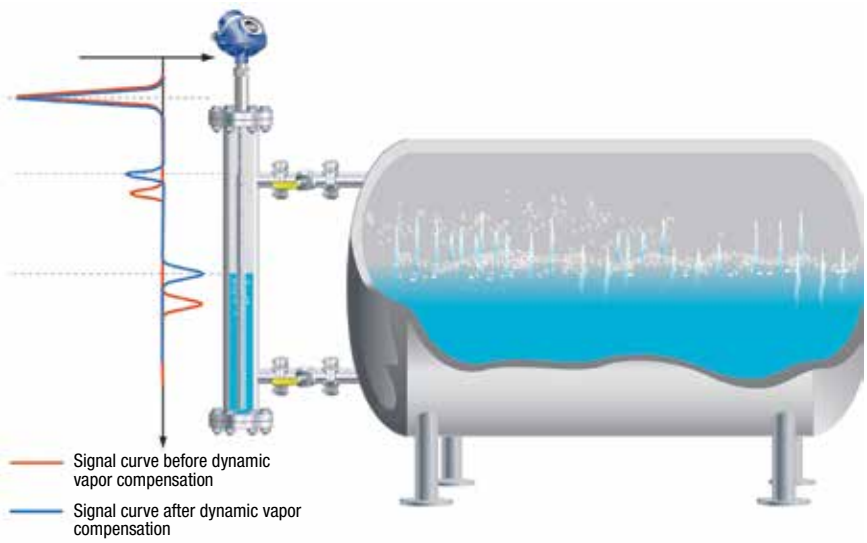


FIGURE 3. A fixed reference reflector helps determine if the dielectric characteristics of the vapor are affecting the pulse travel speed. Dynamic vapor compensation corrects each pulse to maintain accuracy

Thermal range expander. Another specialized technology available for DP level systems used above 400°F (200°C) is a thermal range expander using multiple fill fluids. This type of system uses two fill fluids — high- and low-temperature — separated by an internal diaphragm. A thermal-range expander system can connect to the tank via capillary, or it can be directly mounted to the remote seal, which is ideal for use with tuned assembly or ERS systems. The high-temperature fill fluid can be exposed to the full process temperature while a general-use fill fluid covers the rest of the system. Traditionally, high-temperature fill fluids cannot move fast enough to get a good response at ambient temperatures and would otherwise need to be heat traced to make sure they are always within their operating range. A thermal range expander eliminates the need for heat tracing because it allows both fill fluids to stay within their optimal operation temperature ranges.

Radar level measurement

While DP level measurement starts at the bottom, radar works from the top down. It measures the amount of space inside the tank between the top of the vessel and the surface of the medium, which can be liquid, solid or powder. Radar is relatively new as level technologies go, but because of its advantages in reliability and low maintenance, the chemical process industries (CPI) have widely adopted it, especially for control applications.

Radar takes two forms: guided-wave radar (GWR) and non-contact radar. Both work by sending out a low-energy microwave signal towards the product surface, where it is reflected. Using the reflection, the distance to the surface is calculated and then translated into the level measurement. In non-contacting radar, the signal travels freely through the air or vapor space on its journey to the surface. With GWR, a metal probe extends down through the air or vapor space and into the process medium. If the medium has a low-dielectric or low-reflective property, a portion of the pulse continues down the probe past the surface, which can allow for detection and measurement of an interface level in addition to the basic level measurement. With older units there were limitations on how thin interface layers could be, with a minimum top layer of around 10 in., but advancements have been made to allow for accurate measurements of layers as thin as about 2 in.

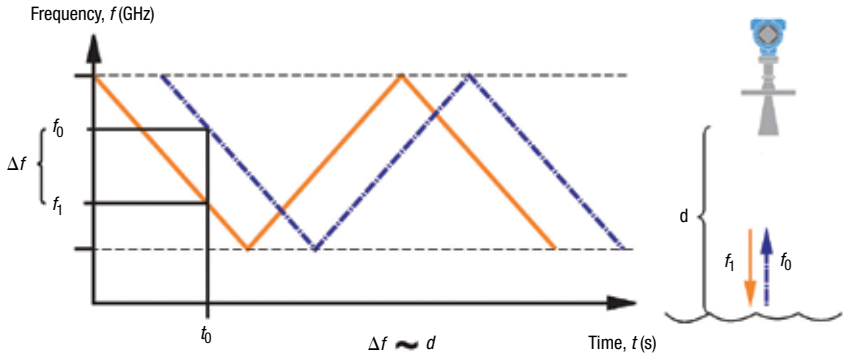


FIGURE 4. FMCW delivers more powerful reflections to provide a higher degree of accuracy than most pulse-based radar transmitters

Another key advantage of radar technology is that no compensation is necessary for changes in density, dielectric constant or conductivity of the medium to measure the level accurately.

GWR technology. With GWR, the probe helps concentrate the signal, which gives it the advantage of seeing beneath the initial level to measure an interface, but also can help with measurements on a turbulent surface. Moreover, when faced with turbulence combined with a low dielectric constant medium, which causes a low signal return, a method called probe-end projection is able to use the location of the end of the probe to calculate the actual liquid surface.

GWR devices are easy to install and can be used in chemical and petrochemical tanks of all sizes, including those with side connections. GWR transmitters have been developed that are able to send their data via WirelessHART and are driven by an internal power module. The ability to install these without any power or signal cables is a significant advance, substantially reducing the installation cost.

The main drawback of GWR is the probe itself, making its use impractical if there are moving agitators or other equipment inside the tank. Some situations allow for material to coat and build-up on the probe, but the effects can be managed by using a transmitter capable of providing enough power to allow for a single lead probe, thereby reducing the opportunity for buildup, or by using diagnostics, such as signal quality metrics, to monitor the signal and determine when buildup is severe enough to affect accuracy so it can be cleaned off before causing problems.

If the dielectric constant of the vapor in the headspace changes significantly, such as happens when the space is filled with saturated steam, it can affect the accuracy of the level reading, but there are advanced GWR transmitters on the market that can use dynamic vapor compensation to correct themselves (Figure 3).

Advances in safety for GWR also include the ability to use a target on the probe to perform high-level proof testing without the need to raise the liquid level. This provides a safer and simpler way to do a full proof test.

Non-contacting radar transmitters. Non-contacting radar level transmitters provide continuous level measurements, but without touching the process medium. Some models use a microwave pulse, while others send a frequency-modulated continuous wave (FMCW) to perform the measurement. With pulse radar, the same time-of-flight technique used by GWR determines distance. With FMCW, the transmitter sends a continuous signal sweep with a constantly changing frequency (Figure 4). The frequency of the reflected signal is compared with the frequency of the signal transmitted at that moment, and the difference between these frequencies is proportional to the distance from the radar to the surface, providing the level measurement.

Until recently, pulse radar transmitters were the only units suitable for two-wire installations, due to the higher power consumption of FMCW, but advances in FMCW transmitter electronics have solved this problem. This is a major advance for many users because the FMCW transmitters actually provide much stronger signals due to the amount of information allowed by the stream of signals, as opposed to single pulses. Non-contacting radar transmitters have key advantages over GWR. Since there is no probe, they are easier to isolate from a corrosive process using a polymer process seal antenna to cover the metallic components, or where the transmitter has to be mounted on a valve so it can be closed off from the process when necessary.

Some newer non-contacting radar transmitters provide an internal data historian and diagnostic routines that can help diagnose issues with the process and increase the safety capability of the devices. Simple proof-test methods can help reduce dangerous undetected failures, making them safer and simpler to use for safety instrumented system (SIS) or safety instrumented function (SIF) applications. Those simple proof tests can be performed remotely, which not only makes proof testing easier, but it saves time, minimizes exposure of workers to hazards in the field and avoids shutdowns of the process, as it can be done while the vessel is still in operation.

Expanding on the topic of safety for level measurements, vibrating-fork level switches provide a major advancement from float switches and can provide an additional layer of protection for overfill prevention and run-dry protection on pumps. Some advanced vibrating-fork level switches employ on-line diagnostics and remote proof testing, which make them excellent complements to the continuous measurements provided by radar and DP level. ■

Edited by Gerald Ondrey

Author

Lydia Miller is a senior product engineer for Rosemount level measurement products at Emerson Automation Solutions (6021 Innovation Blvd., Shakopee, MN 55379; Phone: 800-999-9307; Email: lydia.miller@emerson.com). Prior to this position, she was a senior marketing engineer at Emerson's Chanhassen, Minn. office. Before joining Emerson in 2011, Miller worked in engineering sales at Innovent Air Handling Equipment and at North Atlantic Technologies. She holds a B.S. in mechanical engineering from the University of Minnesota (Minneapolis).

Cloud-based open ecosystems increase availability

Those asking what digitalization can mean for their company rapidly appreciate one point: Nearly every stage of the process industry manufacturing supply chain offers a wealth of starting points. The wide range of new possibilities can be illustrated across the horizontal and vertical business processes, from eProcurement and smart commissioning, to digital-supported maintenance and "plant health apps."

Especially the operations and maintenance phase profits from connectivity and high degree of data consistency. The dataset grows during the entire life cycle with each intervention, calibration and each time an instrument is replaced. What's more, diagnostics information continually generated by intelligent field instruments is steadily added. Intelligently using this mass of information and data poses a challenge. But those who manage this successfully will eventually profit from the high degree of transparency and be in a position to minimize the amount of unplanned system downtime for example. With the help of cloud-based open ecosystems such as those announced by the Open Industry 4.0 Alliance, the generated data will eventually be available within the scope of an Industry 4.0 framework that relies on standards such as OPC UA, RAMI and I/O-Link.

As a founding member of the alliance, **Endress+Hauser** is embedding its Netilion IIoT ecosystem. This cloud-based system encompasses digital services that turn field data into actionable information by means of apps and algorithms bypassing the automation pyramid.

The Netilion IIoT ecosystem contains the following modules:

Netilion Analytics
- Administers the manually or fully-automated (via an edge device) captured assets of the plant
- Links these to an overall view of the system as digital twins
- Provides an overview of the installed base for any type of end user device
- Using KPIs, indicates potential improvements, such as reducing complexity, standardizing the installed instrumentation or issuing a warning in case an instrument is discontinued

Netilion Health
- Provides information regarding the status of the assets, even without being on-site
- In case of a fault, immediately provides instructions on how to rectify the problem on the basis of diagnostics or error codes
- Permits an overall view of the history of the "health condition" of each asset
- Offers sound knowledge that supports instrument maintenance and increases availability

Netilion Library
- Stores and organizes work files and documents and allocates them to the digital twin
- Acts as a file sharing and data management service – in other words makes all documents available from anywhere, whether it's on a notebook, smartphone or tablet
- Saves time when searching for data

www.us.endress.com

KROHNE Instrumentation Solutions for the Chemical Industry

KROHNE is a global leader in the design, development, production, sales and service of process measurement instrumentation. To perform well, you have to be constantly improving. This is particularly true for companies in this industry, and for their suppliers. After all, this industry, more than any other, is in a state of constant change and sometimes extremely short product life cycles. On top of that, there are strict safety and legal regulations that must be adhered to.

KROHNE rises to these challenges and offers its customers complete measuring technology solutions from one source. The extensive range includes measuring devices for storage and interim storage, dosing and mixing, filling and cleaning as well as for auxiliary circuits like steam and hot water. We even have the right technology and the appropriate certifications and approvals for safety rated applications.

Product Portfolio
- Variable area flowmeters
- Electromagnetic flowmeters
- Coriolis Mass flowmeters
- Vortex flowmeters
- Level transmitters and switches
- Pressure transmitters
- Temperature transmitters

KROHNE has also heavily invested in North America with the opening of our brand new manufacturing facility in Beverly, MA for the production of Coriolis Mass flow as well as a variety of electromagnetic and level products. A large inventory of other products is also available for quick delivery.

About KROHNE

KROHNE is a world-leading manufacturer and supplier of industrial process instrumentation solutions. We have 90 years of experience providing flow, level, temperature, and pressure instrumentation to all industry sectors around the globe. For more information, contact KROHNE at 1-800-FLOWING (978-535-6060 in MA); email: info@KROHNE.com, Twitter at @KROHNE_USA, or visit

www.us.krohne.com.

CONNECTEDPLANT CONFERENCE
Harnessing Digital Tools to Drive Success

Seeq

Honeywell International

Grundfos Pumps

The 2020 Connected Plant Conference (www.connectedplantconference.com) is being held February 25–27 in Atlanta, Ga. Focused on the practical implementation of industrial internet of things (IIoT) and other digital technologies in the chemical process industries (CPI) and the energy sector, the event's conference program will discuss digitalization as it relates to a wide variety of industrially relevant topics, including maintenance, risk management, process safety, security and more. The event will kick off with a tour of GE Power's Monitoring and Diagnostics Center in Atlanta, where attendees can observe a control center whose daily processing load includes 200 billion data points from one million connected sensors in 75 different countries. The conference program includes presentations and panel discussions from digitalization experts at a wide variety of CPI companies, including Georgia-Pacific, Petronas, ExxonMobil, Evonik, 3M, Dow, Lonza and more. Digital innovators will also be honored at the Connected Plant Conference, with the Game Changer Awards that highlight significant achievements and problem-solving using digital tools in industrial facilities. The following is a small selection of the products and services offered by the 2020 Connected Plant exhibitors.

New features in this analytics platform promote collaboration

R22 is the latest release of this company's analytics platform (photo) for process manufacturing applications, including chemicals, petroleum refining, pharmaceuticals, mining and more. New R22 features reflect the need for increased collaboration across large organizations with item-level permissions, significant processing-speed increases and additional collaborative features. For organizations seeking to allow only certain users access to given data, R22 now enables users to specify and enforce permissions on all data items, including data sources, calculated data, assets and so on, in addition to the preexisting level permissions. Users can also view who else is working on a worksheet. R22 also features updates to Scatterplot, which now includes options to add trendlines, color by signal, condition or individual capsule and more. The Forecast Splice function can be used to append forecast data (for example, weather from the newly integrated NOAA database) to decision-making tasks. — *Seeq Corp., Seattle, Wash.*

www.seeq.com

Improve enterprise management with digital twins and analytics

This company's Forge for Industrial system (photo) provides enterprise performance-management solutions for operations technology, improving the way that companies collect, analyze and act on process data. Forge for Industrial converts massive quantities of data from equipment, processes and people into intuitive insights, highlighted with potential economic impact for intelligent business and operations, to enable monitoring of enterprise operations from a single screen. In turn, this helps users optimize the efficiency, effectiveness and safety of their business. Forge for Industrial is designed to be quick and cost-effective to implement, with a hardware- and software-agnostic approach that allows for the use of existing systems. The portable and extensible software solution uses process and asset digital twins, as well as role-based and comprehensive analytics to enable enterprise-wide visibility. — *Honeywell International Inc., Charlotte, N.C.*

www.honeywell.com

New machine-health platform delivers AI-based insights

The GMH platform integrates advanced wireless sensors (photo) and artificial intelligence (AI) into maintenance and machine-health monitoring, providing users with the ability to convert data into action plans aimed at improving efficiency and preventing breakdowns. The advanced sensors of the GMH platform offer detailed reporting delivered over the web. Data are transferred to a secure cloud platform (which meets

ISO 27001 requirements), where a robust algorithm uses measurements, such as vibration and temperature, to detect the slightest variation in equipment optimal performance. Quickly installed using a non-invasive method, GMH sensors feature a temperature measurement range of –40 to 257°F. — *Grundfos Pumps Corp., Brookshire, Tex.*
us.grundfos.com

Drive business growth through maintenance optimization

This company's Asset Performance Management (APM) services collect and analyze data from condition-monitoring sources, inspection records and work histories to provide an accurate view of asset health and potential failure modes (photo). With this insight, organizations can develop intelligent asset strategies that effectively mitigate operational risk and prioritize maintenance and inspection resources. Self-learning digital twins can be deployed on critical assets to predict emerging threats early and prescribe mitigating actions. Beyond advanced analytics, the APM solution provides mobile inspection and operator-round technologies aimed at improving the accuracy and efficiency of manual asset-data collection. — *GE Digital, San Ramon, Calif.*
www.ge.com/digital

Wireless, battery-free sensors expand connectivity capabilities

This company's IIoT solutions combine battery-free, wireless sensors and cloud analytics to enable low-cost smart instrumentation devices with long operational lifetimes (photo). These technologies allow connectivity for industrial assets that were previously too expensive or dangerous to connect. The company's range of products are designed to monitor steam systems, flare systems and a range of rotating equipment, such as motors, pumps, fans and compressors. — *Everactive, Santa Clara, Calif.*
www.everactive.com

Deliver value through data with this connectivity platform

AssetHub is a cloud-based enterprise software platform (photo) that builds and sustains connectivity and visibility into asset and operations data spread across multiple computer systems and facilities. AssetHub connects to and integrates data from a variety of source systems to create one reliable, evergreen enterprise asset model that makes it possible for people across an organization to easily access asset data and gain valuable insights to improve operations. Along with AssetHub technology, this company offers the AF Accelerator Solution, which is a combination of AssetHub with access to the company's industrial data experts and methodology. In just 12 weeks, with the AF Accelerator program, teams can efficiently initiate AssetHub capabilities into their operating facilities. — *Element Analytics, Inc., San Francisco, Calif.*
www.elementanalytics.com

Easy-access trend analysis of time-series data

This company's software (photo) is based on a high-performance analytics engine that allows users to query data directly, without the support of data scientists. The plug-and-play software adds immediate value upon deployment, eliminating the need for infrastructure investment and long implementation projects. Search, diagnostic and predictive capabilities enable users to speed up root-cause analyses, define optimal processes and configure early warnings to monitor production. The platform also helps team members to capture feedback and leverage knowledge across teams and sites. In addition, this company offers standard integrations with a wide range of historians, such as OSIsoft PI, Yokogawa Exaquantum, AspenTech IP.21, Honeywell PHD, GE Proficy Historian and Wonderware InSQL. — *TrendMiner US, Houston*
www.trendminer.com

Optimization-focused machine learning brings critical insights

The latest release of this company's machine-learning process-optimization software (photo, p. 52) features an automated optimization toolkit. This feature enables the software to discover optimal setpoints for impor-

GE Digital

Everactive

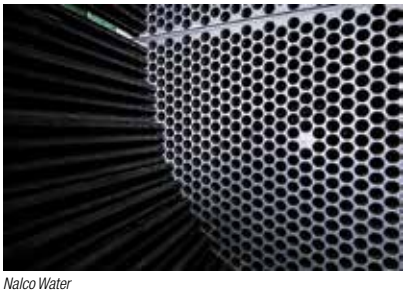
Element Analytics

TrendMiner

Fero Labs

Hydro

North American Dismantling



Nalco Water

Uniper

tant process factors to ensure performance targets are always met. The software automatically cleans and processes data, and with the latest release, multiple data sources can be merged, filtered and processed all within the software, vastly accelerating the software's data ingestion capabilities. This allows engineers to train more machine-learning analyses in a shorter time period and explore more use cases. The scalability of the software is further reinforced with an expanding list of historian connectors, such as the new OSIsoft PI connector that allows the software to pull data directly from the historians. — *Fero Labs, New York, N.Y.*
www.ferolabs.com

Advanced monitoring and maintenance for pumps

This company's wireless condition-monitoring system and smart enterprise predictive-maintenance software provides alerts, advanced analysis and automated reporting to prevent failures, increase uptime and extend asset life of pumps. The platform's wireless temperature and vibration sensors (photo) work with a wireless gateway to securely transmit monitoring data to the cloud for storage and analysis. Authorized users can access real-time and historical data remotely, ensuring that equipment information and analytical tools are readily available wherever users are located. Automated communication when equipment exceeds set alert and alarm levels allows users to facilitate a swift response when problems develop. — *Hydro Inc., Chicago, Ill.*
www.hydroinc.com

Digital insights into critical heat-exchanger operation

OMNI is a digital platform designed to improve performance in heat exchangers (photo). The tool helps predict fouling and operational issues, to prevent unscheduled outages and to prolong runtimes and asset life, says the manufacturer. The platform combines water- and process-side data, which are run through a secure, Microsoft-powered calculation engine. The data are analyzed in real time, while a team of engineers monitor the data continuously for irregularities. The information is displayed on a powerful dashboard that provides real-time access to the assets across an organization. Lastly, this company's audit team reviews the entire plant annually to monitor the overall health of the complete water system. — *Nalco Water, an Ecolab Company, Naperville, Ill.*
www.ecolab.com/nalco-water

Demolition services with a focus on compliance and safety

This company performs demolition projects, including environmental assessment and remediation of contamination. The services offered range from selective demolition to retrofit and conversion projects to total site demolition. With experience in numerous industrial sectors, the company's experts can work with the proper agencies to meet varying compliance measures in different states and regions, include very remote areas. — *North American Dismantling Corp. (NADC), Lapeer, Mich.*
www.nadc1.com

This smart energy-monitoring tool improves decision making

Enerlytics (photo) is a digital software platform based on IIoT technologies that aims to help plant managers and operators respond optimally to transforming energy markets and meet environmental standards. Enerlytics presents user-built analytics, offering users the autonomy to optimize plant performance, and to make better informed decisions for improved flexibility and financial gain, while enabling a safe, secure and sustainable operations. The scalable tool can process huge amounts of live data to create predictions of future plant asset behavior. Enerlytics can capture data from multiple sources and perform streaming and batch analytics using various "clusters." This allows users to more efficiently access and manipulate data and share it with a wider team, all on one central dashboard. — *Uniper SE, Düsseldorf, Germany*
www.uniper.energy ■

Mary Page Bailey

Economic Indicators

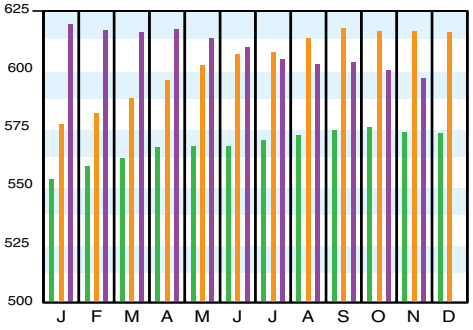
2017 2018 2019

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	Nov. '19 Prelim.	Oct. '19 Final	Nov. '18 Final
CE Index	596.1	599.3	616.5
Equipment	723.4	727.6	752.3
Heat exchangers & tanks	620.0	627.7	671.4
Process machinery	720.8	721.7	732.6
Pipe, valves & fittings	955.9	958.4	973.6
Process instruments	419.2	420.5	420.8
Pumps & compressors	1072.8	1072.3	1036.3
Electrical equipment	561.6	560.8	552.8
Structural supports & misc.	764.6	771.7	832.5
Construction labor	336.3	337.6	338.2
Buildings	586.7	589.3	600.7
Engineering & supervision	313.6	313.8	317.1

Annual Index:
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1

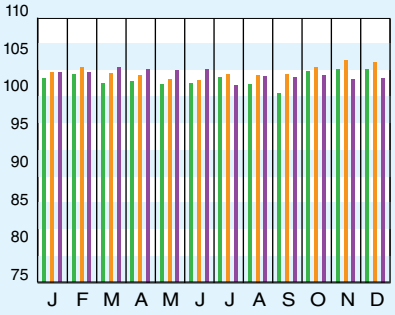


Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

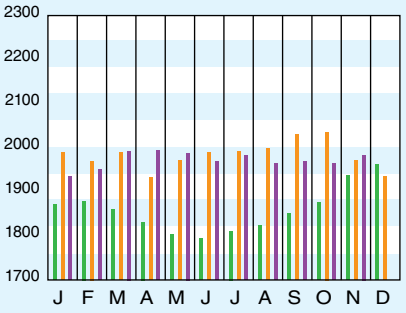
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Dec. '19 = 102.0	Nov. '19 = 101.4	Oct. '19 = 101.6	Dec. '18 = 104.8
CPI value of output, $ billions	Nov. '19 = 1,983.8	Oct. '19 = 1,970.7	Sept. '19 = 1,963.6	Nov. '18 = 1,973.0
CPI operating rate, %	Dec. '19 = 75.8	Nov. '19 = 75.4	Oct. '19 = 75.6	Dec. '18 = 78.8
Producer prices, industrial chemicals (1982 = 100)	Dec. '19 = 242.9	Nov. '19 = 245.7	Oct. '19 = 249.5	Dec. '18 = 262.4
Industrial Production in Manufacturing (2012 =100)*	Dec. '19 = 105.0	Nov. '19 = 104.8	Oct. '19 = 103.8	Dec. '18 = 106.4
Hourly earnings index, chemical & allied products (1992 = 100)	Dec. '19 = 187.2	Nov. '19 = 187.1	Oct. '19 = 187.8	Dec. '18 = 186.9
Productivity index, chemicals & allied products (1992 = 100)	Dec. '19 = 96.0	Nov. '19 = 95.3	Oct. '19 = 95.3	Dec. '18 = 98.2

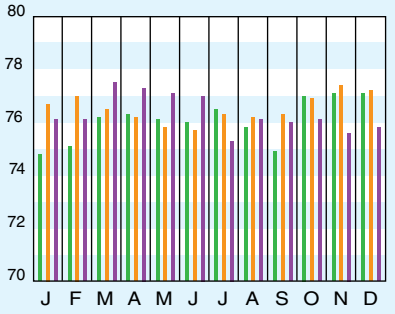
CPI OUTPUT INDEX (2000 = 100)†



CPI OUTPUT VALUE ($ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for November 2019 (the most recent available) decreased from the previous month's value, the eighth decline in the last ten months. All four major subindices of the overall CEPCI (Equipment, Buildings, Construction Labor and Engineering & Supervision) decreased in November. The current CEPCI value is 3.3% lower than the corresponding value from a year ago at the same time. Meanwhile, the Current Business Indicators (CBI; middle) saw small increases in both the CPI Output Index for December 2019, and the CPI Output Index for November. Producer prices for chemical and allied products edged lower in December, while the Productivity Index ticked upward.